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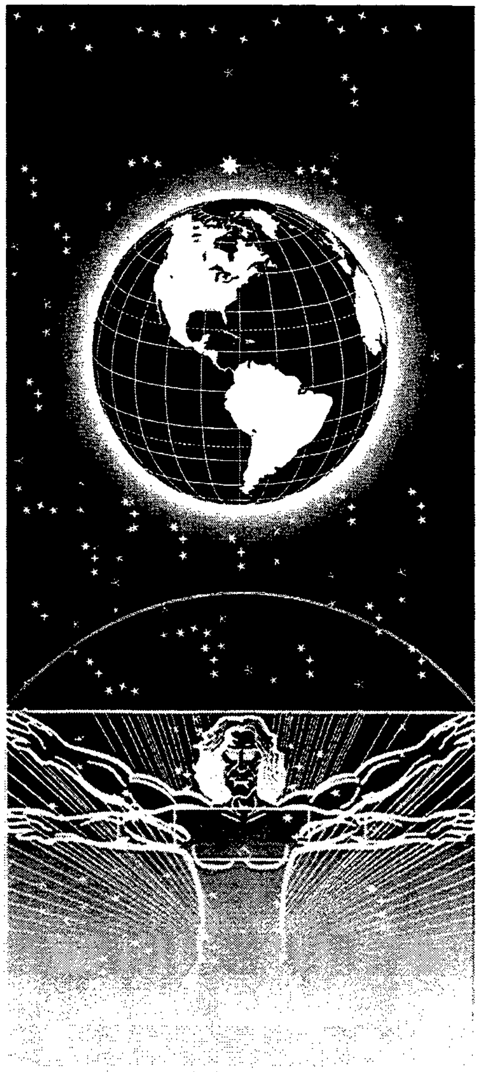

UNITED STATES AIR FORCE RESEARCH LABORATORY

TPH CRITERIA WORKING GROUP FIELD DEMONSTRATION SITE REPORT: ROBINS AIR FORCE BASE, WARNER-ROBINS, GA

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October 1998
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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

STEPHEN R. CHANNEL, Maj, USAF, BSC
Branch Chief, Operational Toxicology Branch
Air Force Research Laboratory

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13. ABSTRACT *(Maximum 200 words)*

A Phase I visit to Robins Air Force Base, Georgia, was undertaken to brief base environmental management and State representative on the Total Petroleum Hydrocarbon Criteria Working Group approach for establishing Risk Based Screening Levels at petroleum hydrocarbon contaminated sites. The Phase I visit also included review and evaluation of several potential candidate sites for the demonstration of the approach. The Underground Storage Tank Site 70, a JP-4 and JP-8 spill site, was chosen as the most viable candidate for the demonstration project. Data on the history, physical setting, and previous investigations at the site were collected and a work plan developed for the site.

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PREFACE

This effort was performed by Operational Technologies Corporation (OpTech) under U.S. Air Force Contract Number F41624-94-D-9003/008. OpTech activities were conducted under the Project Management of Mr. Erik Vermulen, 1370 North Fairfield Road, Suite A, Beavercreek OH 45432. Major Steve Channel of the Air Force Research Laboratory, Human Effectiveness Directorate, Operational Toxicology Branch (AFRL/HEST), served as contract monitor.

The authors gratefully acknowledge Mr. Paul Barker and Mr. Kevin Long of Warner-Robins Air Logistics Center, Environmental Management Division, for their assistance in the Phase 1 effort and developing the work plan.

LIST OF ABBREVIATIONS AND ACRONYMS

°F	degrees Fahrenheit
AFB	Air Force Base
AFRL/HEST	Air Force Research Laboratory, Operational Toxicology Branch
ASTM	American Society for Testing and Materials
atm	atmosphere
BGS	below ground surface
BTEX	benzene, toluene, ethylbenzene and xylene
CAP	Corrective Action Plan
cm	centimeter
C_{sat}	saturation concentration
DQO	data quality objective
DRO	diesel range organics
EC	effective carbon number of chemical molecule
EPA	Environmental Protection Agency
EPD	Environmental Protection Department (Georgia)
ft	feet
g	gram
GC	gas chromatograph
H_2O	water
HAZWRAP	Hazardous Waste Remedial Actions Program
H_c	Henry's Law Constant
L	liter
LNAPL	light non-aqueous phase liquid
kg	kilogram
m	meter
m^3	cubic meter
mm	millimeter
NAPL	non-aqueous phase liquid
OVA	organic vapor analyzer
OpTech	Operational Technologies Corporation
PAH	polycyclic aromatic hydrocarbon
PDE	partial differential equation
PID	photo-ionization detector
QA/QC	qualtiy assurance/quality control
QAPP	Quality Assurance Program Plan
QC	quality control
RBCA	Risk Based Corrective Action
RBSL	risk based screening level
RfD	reference dose
s	second
SCAPS	Site Characterization and Analysis Penetrometer System
TPH	total petroleum hydrocarbons
TPHCWG	Total Petroleum Hydrocarbon Criteria Working Group
USAF	U.S. Air Force
UST	underground storage tank
VF_{sesp}	volatilization factor (subsurface soil to enclosed-space vapors)
VOC	volatile organic compounds
WR-ALC/EMQ	Warner Robins Air Logistics Center, Environmental Quality Branch
yr	year

TOTAL PETROLEUM HYDROCARBON CRITERIA WORKING GROUP FIELD DEMONSTRATION PROJECT: ROBINS AIR FORCE BASE, GEORGIA

1.0 INTRODUCTION

Operational Technologies Corporation (OpTech) is contracted by the U.S. Air Force Research Laboratory, Operational Toxicology Branch (AFRL/HEST), to conduct demonstration projects utilizing the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG or Working Group) approach for sample analysis and risk assessment. The Working Group has developed an approach for establishing risk based screening levels (RBSLs) for weathered petroleum contaminated sites. This approach utilizes standard site assessment and sampling techniques for petroleum hydrocarbon contaminated sites. It varies, however, in the analytical method for quantifying total petroleum hydrocarbon (TPH) and the risk assessment undertaken to recommend clean-up levels.

The approach evaluates TPH by hydrocarbon fractions, selected based on partitioning properties, and assesses risks with assigned fraction toxicities. A special analytical method is performed which identifies and quantifies each TPH fraction. The purpose of the program is to demonstrate the establishment of scientifically defensible soil cleanup levels that are protective of human health at petroleum contaminated sites. This approach, when accepted by the regulatory community, can assist governmental and private industry to focus remediation efforts on those sites which pose a significant risk to human health and the environment.

1.1 Demonstration Site

Underground Storage Tank (UST) Site 70 at Robins Air Force Base (AFB) was chosen for demonstration of the Working Group approach. Robins AFB lies in central Georgia south of Macon and immediately east of the city of Warner Robins. The base is home to the Warner Robins Air Logistics Center, Air Force Material Command, and several tenant air groups. The base has numerous UST sites used for fuel storage. Currently, the base is closing or remediating many of the sites that have had past releases. The State of Georgia expressed interest in the demonstration project as they are currently working to address TPH contaminated sites that do not contain chemicals of concern currently regulated (i.e., benzene, toluene, ethylbenzene, xylene (BTEX) and polycyclic aromatic hydrocarbons (PAHs)).

1.2 Objectives of the Phase 1 Visit

The major objectives of the Phase 1 visit to Tinker AFB included:

- Briefing base and State representatives on the Working Group approach.
- Obtain buy-in from all interested parties on the application of the Working Group approach.
- Identification of a site that fits the selection criteria.

- Collect contaminant and geotechnical data from previous site investigations.
- Develop a work plan for the Phase 2 field work based on data from previous investigations.

1.3 Project Execution

The Working Group Demonstration Project includes identification of states with interest in the approach and demonstration at military bases where investigation of TPH contaminated sites is ongoing. Military bases throughout the United States were contacted to assess the current state of UST spill sites at the bases and the interest in the approach from the environmental management personnel at the bases. The appropriate state agencies were contacted to assess their interest and the current requirements for investigations and closure of TPH contaminated sites. If both the state and the base were interested and the current regulations for TPH contaminated sites did not require assessment of TPH or the state was working to develop regulations regarding TPH contaminated sites, the base was considered a potential demonstration site. Further discussions with the base and the state led to identification of target UST sites and scheduling a Phase 1 visit to the base for the briefing.

2.0 APPROACH

2.1 Briefing

A briefing on the Working Group approach washeld at the Warner Robins Air Logistics Center, Environmental Quality Branch (WR-ALC/EMQ), Robins AFB. It was attended by management from WR-ALC/EMQ and a representative from the State of Georgia Environmental Protection Department (EPD) (see Table 2.1). The briefing described some of the problems with characterizing TPH contaminated sites,and expectations of what the Working Group approach could provide to the base and regulators.

TABLE 2.1 POINTS OF CONTACT FOR ROBINS AFB DEMONSTRATION PROJECT

Name	Organization	Address	Phone Number
Mr. Paul Barker	WR-ALC/EMQ Site 70 Project Manager	216 Ocmulgee Court Robins AFB, GA 31098-1646	(912) 926-1197 extension 211
Mr. Kevin Long	WR-ALC/EMQ Project Manager	216 Ocmulgee Court Robins AFB, GA 31098-1646	(912) 926-1197 extension 215
Ms. Chifeng Gu	GA EPD	4244 International Parkway, Suite 104 Atlanta, GA 30354	404-382-2589

2.1.1 Robins AFB Interest in the Approach

Robins AFB has numerous UST sites that are currently being closed or investigated for further action under Georgia State UST regulations. Georgia regulations currently focus on contaminants of concern such as BTEX and PAHs. The State currently has no rules regulating TPH contaminated sites, but previous TPH rules caused much controversy within the regulated and consulting communities.

Robins AFB Environmental Quality Branch is interested in the Working Group approach to assist them in closing sites that have high TPH contamination. Several sites at Robins AFB have undergone some type of remedial action, such as free product removal, and are waiting on approval for closure under State regulations. Some of these sites require additional investigatory drilling to characterize PAH contamination. Robins AFB is interested in the applicability of the approach at those sites, especially to define the residual TPH contamination that exists after removal of free product. As such, the WR-ALC/EMQ Site 70 Project Manager, Mr. Paul Barker, offered to provide drilling support during the PAH delineation program for the Working Group demonstration project.

2.1.2 State of Georgia Interest in the Approach

Ms. Chifeng Gu was present at the Phase 1 briefing representing the Georgia Environmental Protection Department. Ms. Gu works with the group within EPD that evaluates new methods and laboratories. She stated that the State had no TPH cleanup standards at this time because of controversy that existed regarding previously promulgated TPH standards. As such, they are very interested in the Working Group approach for application in Georgia.

2.2 Proposed Demonstration Site

After briefing base and State representatives, Mr. Paul Barker, WR-ALC/EMQ Site 70 Project Manager, Mr. Kevin Long, WR-ALC-EMQ Project Manager; Mr. Lance Erley, WR-ALC/EMQ Contractor Inspector; and the OpTech representative toured three of the sites where the approach could be demonstrated most effectively. UST Site 70 was chosen as the best candidate site for the demonstration project because it fit most of the criteria used for site selection. The site was contaminated from JP-4 and JP-8 spills and leaks that dated back many years; the site subsurface soils included fill material, sand, gravel, and recent peat layers; the contaminated area was near an office area; and groundwater flowed towards the swamp that is part of the Ocmulgee River Floodplain. Site description information was extracted from existing documentation including the "Corrective Action Plan - Part A for UST Sites 70 and 72 at Robins AFB, GA" prepared for Robins AFB Environmental Management (HAZWRAP, 1996).

2.3 Site Description

Most of Robins AFB lies within the Ocmulgee River Valley, which is characterized by nearly flat to gently sloping terraces and swampy, bottom land floodplains. The floodplain and terrace system locally ranges between 1 and 3 miles in width. UST Site 70 is located on filled land within the Ocmulgee River floodplain (see Figure 2.1). Total relief within 1 mile of the site is

less than 20 ft. The work plan, located in Appendix A, has a complete description of the physical setting of the base.

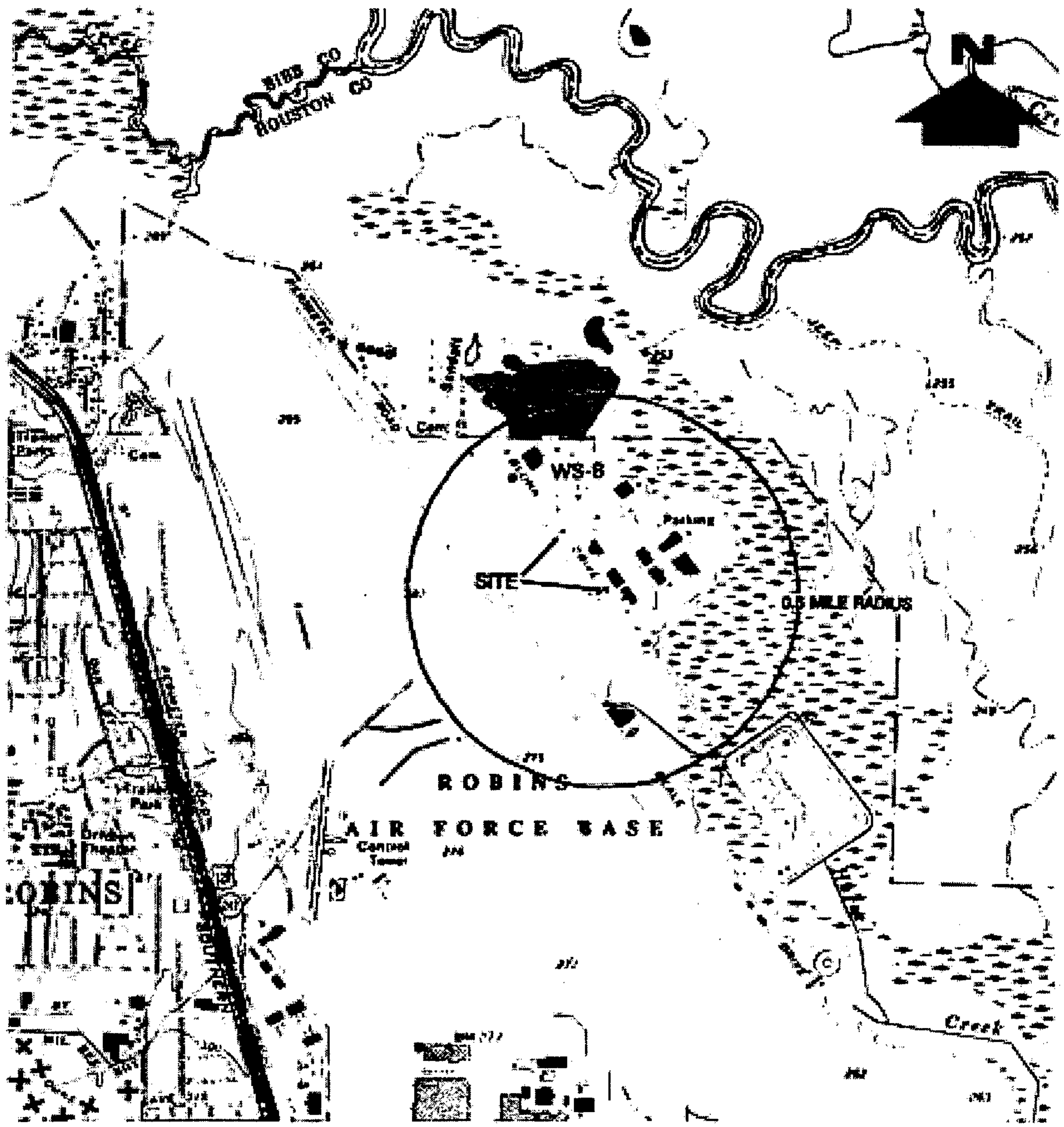


Figure 2.1 Site 70, Robins AFB, Georgia

Site 70 is located in the northeastern portion of Robins AFB. UST Site 70 serves as a large aircraft refueling/defueling hydrant system providing ground support to the 19th Air Refueling Group and the 93rd Air Control Wing. The aircraft refueling/defueling hydrant system at Site 70 consists of a small storage building (Building 28), a pumphouse/control room (Building 2070),

six 50,000 gallon steel USTs containing jet fuel, a 2,000 gallon steel UST containing waste fuel, a 400 gallon UST containing water, and approximately 5200 feet of 4 to 6-inch diameter steel lines supplying six hydrants located on the adjacent parking apron. The USTs and associated lines were originally installed in 1958. The tanks were used for storage of JP-4 jet aircraft fuel until June 1994 and JP-8 jet aircraft fuel since.

Site 70 is in an area of fill material over recent floodplain deposits of the Ocmulgee River which include sand, clay, and peat. These deposits overlie a Cretaceous sandstone which is used as a regional aquifer. The groundwater table at Site 70 ranges from 6 to 9 feet deep and discharges to the floodplain east of the site. The floodplain to the east is a critical environment which may be impacted by contaminated discharge.

2.4 Data Collection

The WR-ALC/EMQ Project Manager, Mr. Paul Barker, provided data on Site 70. Data were found in the "Corrective Action Plan – Part A for Underground Storage Tank Sites 70 and 72" (HAZWRAP, 1996) and the "Draft Corrective Action Plan - Part B for Underground Storage Tank Sites 70 and 72 at Robins AFB" (HAZWRAP, 1997). Data presented in the two Corrective Action Plans (CAPs) included information from previous investigations and the Hazardous Waste Remedial Actions Program (HAZWRAP) data gap collection effort.

2.4.1 Previous Investigations

Numerous maintenance and investigatory actions have been undertaken at Site 70. The following information summarizes investigations and actions pertinent to the contamination at Site 70. The work plan in Appendix A contains a more complete discussion of discoveries, investigations, and actions at the site.

Vapor monitoring wells were installed in the tankfield of UST Site 70 during a base-wide UST environmental upgrade program in 1992. The wells were approximately 12 feet deep and extended into the shallow groundwater at the site. Two additional vapor monitoring wells were installed at the site in September 1993. Free product was detected in most of the vapor monitoring wells in September 1993.

Electrical contractors, excavating a pit for new underground lines, encountered free product on groundwater on October 28, 1993. The excavation was approximately 35 to 40 feet south-southwest of the tankfield at UST Site 70.

An Initial Site Characterization in the area of Site 70 was undertaken in late 1993 in response to the detection of free product in the vapor monitoring wells. Following completion of the initial site characterization, the Air Force conducted a UST contamination assessment at Site 70. A total of 15 borings were drilled near UST Site 70 during January 1994 for the assessment. Ten of the borings were completed as monitoring wells and groundwater samples were collected and analyzed. Water levels and free product measurements were taken and free product was removed from the monitoring wells using manual and skimmer techniques. The unexpectedly large areal extent of the dissolved hydrocarbons and contractual limitations contributed to

incomplete delineation of the dissolved phase plume. Therefore, a second phase of investigation was initiated.

The assessment activities at Site 70 were continued with the addition of 15 borings installed in August 1994. Thirteen of these borings were completed as monitoring wells and groundwater samples collected for laboratory analysis. The findings of the site assessment activities indicated a large residual phase petroleum hydrocarbon plume surrounding the tankfield at Site 70 and a large dissolved phase petroleum hydrocarbon plume extending downgradient east and southeast of the site.

The U.S. Army Corps of Engineers, Kansas City Geotechnical Branch, demonstrated the Site Characterization and Analysis Penetrometer System (SCAPS) at Site 70 in February 1995. The SCAPS system uses a laser induced fluorescence tool to indicate free product and/or residual contamination thickness and depth. The demonstration was limited to an area around the EA-2 monitoring well. The results of the demonstration showed a 2.5 ft interval from 6 to 8.5 ft below ground surface (BGS) of elevated hydrocarbon fluorescence that correlated well with the maximum free product thickness measured in the nearby monitoring well.

In July 1995, Batelle provided some additional site characterization information in conjunction with a short-term field pilot test of the Bioslurper system at Site 70. Three product recovery wells were installed and three soil gas monitoring well clusters were installed.

In October 1996, the Department of Energy HAZWRAP undertook an investigation of soils and groundwater upgradient and to the east of the known source areas and filled in some data gaps. Seventeen locations were investigated using either the Geoprobe direct push system or using hand augers for shallow temporary piezometer installation. Seven of those locations were upgradient of the source areas of UST Sites 70/72 and eight others were to the east and northeast of the source contamination at UST Sites 70/72. Some sampling points included identification of clay and/or peat layers for delineation of groundwater flow barriers and/or extremely adsorptive units. Groundwater conditions were investigated at multiple piezometers and data on fuel-related compounds and natural attenuation indicators were collected. The investigation included contaminant transport in groundwater and natural attenuation modeling for the site.

2.4.2 Remedial Actions Undertaken

Initial remedial actions to remove free product petroleum hydrocarbons were undertaken in September 1993 at the vapor monitoring wells and in October 1993 at the utility excavation. Remedial actions at the vapor monitoring wells included manual bailing of free product and cleanup with petroleum-adsorbent pads. Approximately 16 gallons of free product were removed during that action. The remedial action at the utility excavation south-southwest of the tankfield at UST Site 70 included removal using a vacuum waste pumping truck. Approximately 20 gallons of liquid hydrocarbons were removed from the excavation.

In March 1994, a DPI Petro-belt hydrocarbon-only belt skimmer was installed on monitoring well EA-2 to recover the free product. A total of 1,796 gallons of liquid petroleum hydrocarbons had been collected at Site 70 through July 1995 using these methods. Following initial field testing in July 1995, the Batelle Bioslurper system began running full time at monitoring well EA-2 in

late spring of 1996. Approximately 3,400 gallons of free product were recovered through the Bioslurper. The Bioslurper was removed in October 1997 when the free product layer had been removed in the vicinity of monitoring well EA-2.

2.4.3 Source Of Contamination

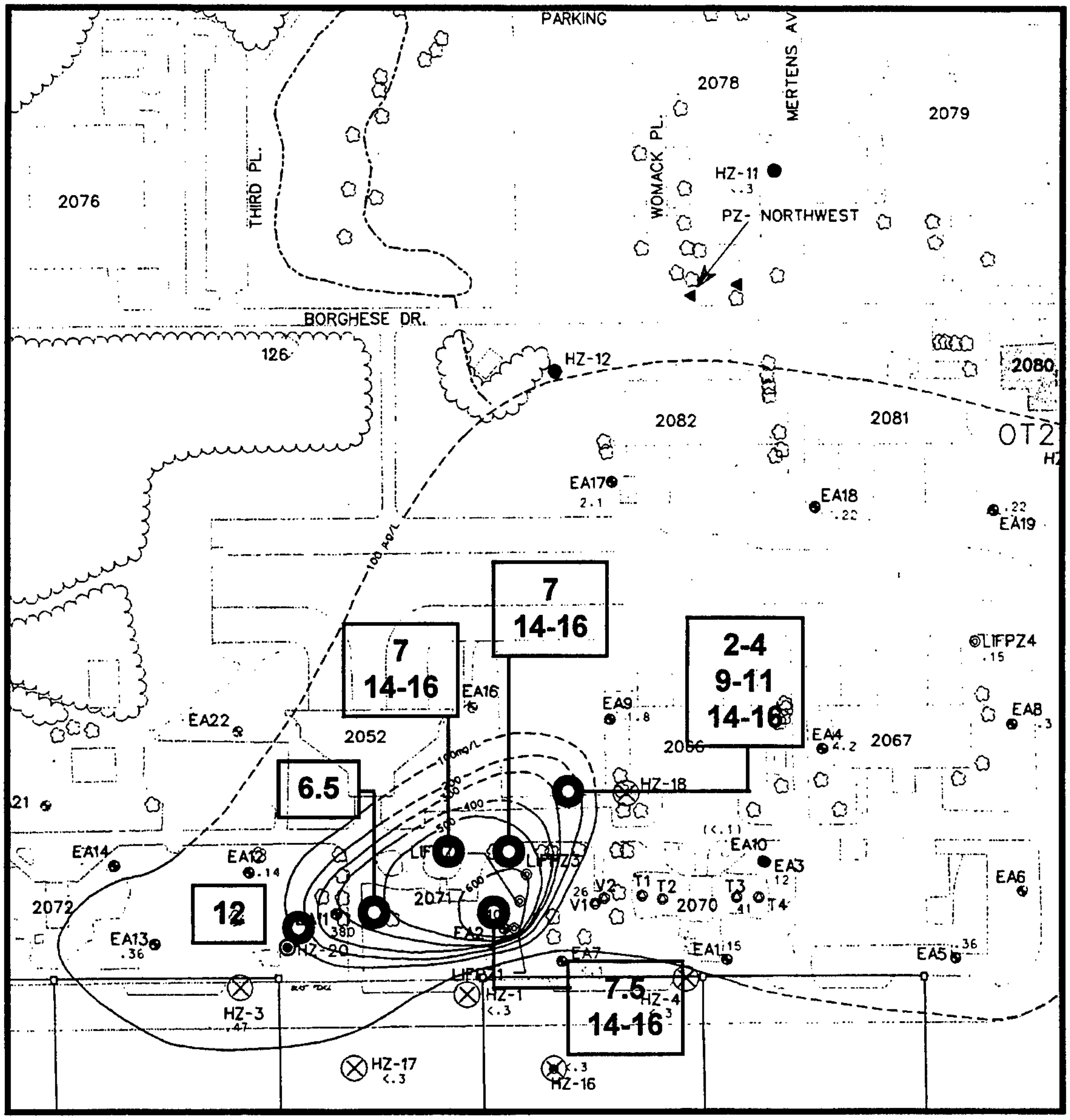
The source of free product and residual contamination in soils at the UST Site 70 appears to result from some combination of historical leaks, spills, and overfills related to the jet fuel storage and distributions system at the site. A leak was documented at the lateral control pit #3 at Site 70 in 1995. Soils contamination and free product occur relatively near the lateral control pit, suggesting that it may represent a significant source for this nearby contamination. Free product and soils contamination detected in vapor wells and borings at and around the Site 70 tankfield appear to have occurred from surface spills and/or overfills there. Free product has also been found up to 150 feet away from the tankfield, including several areas near the valve junction boxes just off the east end of the concrete tarmac. These junction boxes may also have been significant sources over time.

Environmental staff also report that various fuel spills and overfills have occurred on the tarmac associated with the fueling of aircraft. These spills were washed over the edge of the concrete tarmac and may have contributed significantly to the contamination.

3.0 WORK PLAN

3.1 Sampling and Analysis Plan

After review of the data in the two HAZWRAP CAPs, a work plan was developed that detailed the sampling plan for the demonstration project (Appendix A). The work plan included installation of six soil borings to test a potential source of contamination and the area of residual contamination left after free product removal (see Figure 3.1). Eleven soil samples were proposed to test the lateral and vertical extent of the TPH contamination. Table 3.1 presents the sample intervals and sample objectives for the proposed soil borings.



Legend

Proposed Soil Boring Location

DRO Isopleths (mg/L) in upper aquifer (Dashed where unknown or inferred)

2-4
7.5
12

Depth (ft BGS) to Zones of Interest in Proposed Soil Borings

Figure 3.1 Proposed Locations of Demonstration Project Soil Borings*

(* Adapted from HAZWRAP, 1997)

TABLE 3.1 PROPOSED SAMPLE BORINGS FOR SITE 70, ROBINS AFB, GA

Boring Number	Sample Intervals	Sample Objective
DSB1	12 ft BGS	Soil contamination near Lateral Pit #1
DSB2	6.5 ft BGS	Free product residual at groundwater surface
DSB3	7, 14-16 ft BGS	Free product residual and lower soil contamination
DSB4	7.5, 14-16 ft BGS	Free product residual and lower soil contamination
DSB5	7, 14-16 ft BGS	Free product residual and lower soil contamination
DSB6	2-4, 9-11, 14-16 ft BGS	Near surface contamination, mid and lower soil contamination near Building 2066

The work plan describes project management, project quality control plan, sample analyses, and risk assessment based on the Working Group analytical approach. The Working Group approach requires fractionation of the samples into effective carbon (EC) groups for aliphatic and aromatic hydrocarbons. The risk assessment is based on the additive risks from the EC groups and exposure pathways that would be completed for the current and future land uses. The work plan describes the analytical method and the risk assessment approach.

3.2 Data Analysis Focus

Two areas of the Working Group approach may be a concern at this site. As previously discussed, the approach is thought to be most appropriate at sites where there is no free product and contamination levels are not above soil saturation levels. Secondly, with buildings in the area, the simple models used to describe transport of soil vapors for assessing the indoor air pathway of exposure may provide excessively conservative predictions. Background information on these two areas is summarized in Appendices B and C, respectively.

4.0 STATUS OF DEMONSTRATION PROJECT

The work plan was submitted to Mr. Paul Barker, WR-ALC/EMQ UST Site 70 Project Manager, for review and comments in June 1998. Mr. Barker had offered drilling support if the demonstration project were undertaken during the PAH data gap drilling effort. The data gap drilling effort was contracted to Geophex, Warner Robins, Georgia. As of September 1, 1998, the drilling program was scheduled to take place at the end of November 1998, after approval of the Geophex workplan. This schedule is beyond the period of performance for the OpTech contract with AFRL/HEST and the Phase 2 field work has been postponed indefinitely.

5.0 REFERENCES

HAZWRAP, November 1996. Draft Corrective Action Plan - Part A for Underground Storage Tank Sites 70 and 72 at Robins AFB. Hazardous Waste Remedial Actions Program, Department of Energy, Oak Ridge, Tennessee.

HAZWRAP, February 1997. Draft Corrective Action Plan - Part B for Underground Storage Tank Sites 70 and 72 at Robins AFB. Hazardous Waste Remedial Actions Program, Department of Energy, Oak Ridge, Tennessee.

APPENDIX A FIELD INVESTIGATION WORK PLAN - TOTAL PETROLEUM HYDROCARBON CRITERIA WORKING GROUP DEMONSTRATION PROGRAM: ROBINS AIR FORCE BASE, WARNER ROBINS, GEORGIA

A1.0 INTRODUCTION

This Work Plan outlines activities for conducting a field demonstration of the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG or Working Group) approach at Underground Storage Tank (UST) Site 70, located on the Robins Air Force Base (AFB), Warner Robins, Georgia. The Working Group has developed a risk based criteria for assessing weathered petroleum hydrocarbon contaminated sites. This approach utilizes standard site assessment and sampling techniques for petroleum hydrocarbon contaminated sites. It varies, however, from standard assessment techniques in the petroleum hydrocarbon analyses and the analyses undertaken to assess the level of human health risk leading to recommended clean-up levels. This approach results in the development of human health risk based screening levels (RBSLs) for the site.

Operational Technologies Corporation (OpTech) is contracted by the U.S. Air Force Research Laboratory, Operational Toxicology Branch (AFRL/HEST) to conduct demonstrations utilizing the Working Group approach for sample analysis and risk assessment. The Working Group protocol utilizes total petroleum hydrocarbon (TPH) fractionation analysis and assesses risks by assigning toxicity values based on fraction health effects. The purpose of the program is to demonstrate the risk-based hydrocarbon fractionation protocol and to collect data necessary to compare the Working Group approach to currently accepted state regulatory methods. This approach, when accepted by the regulatory community, can assist governmental and private industry to focus remediation efforts on those sites which pose a significant risk to human health and the environment.

A1.1 Project Objectives and Scope

UST Site 70, a weathered TPH contaminated site at Robins AFB, was selected as a Working Group field demonstration site. The purpose of this Work Plan is to describe the information sought on the selected UST site and the sampling requirements needed to demonstrate the Working Group analytical and risk assessment protocol. Phase I of the demonstration program includes the identification of suitable weathered TPH sites at Robins AFB, an initial site visit, and the collection of existing geotechnical and analytical data to support the development of a field sampling plan and risk assessment. The Phase II field sampling program at the UST site will consist of field sampling activities designed to adequately characterize the nature of TPH contamination and perform a risk evaluation. The Working Group approach will be applied within the American Society for Testing and Materials (ASTM) Risk-Based Corrective Action (RBCA) methodology to generate risk-based screening levels based on the fractionated results. The major objectives of the Phase I and II demonstration program are:

- Delineation of TPH contamination from existing investigative data and identification of the best locations for gathering a limited number of samples for the demonstration program.

- Collection of soil samples at each site for conventional TPH and the Working Group fractionation analysis.
- Characterization of the variation in the TPH fractions over the horizontal and vertical extent of soil contamination.
- Develop correlation between results of conventional and fractionation analysis results and correlation between total organic carbon content of soil and degree of weathering.
- Obtain geotechnical data (e.g., moisture content, permeability, bulk density, particle size distribution, total organic carbon, and hydraulic conductivity) from the selected sites necessary for fate and transport evaluation of the TPH contaminants.
- Assessment of potential risks from hydrocarbon fractions present based on the ASTM RBCA method.
- Comparison of the risk analysis and soil screening levels developed based on TPH fractionation to the state clean up criteria identified as part of the corrective action plan.

Phase I of the demonstration program included coordination and discussions with base level remediation managers and state regulators involved with evaluation of new analytical methods to familiarize them with the background and purpose of the demonstration program. At the preliminary site visit, a briefing was held to familiarize the site managers and regulatory community with the Working Group protocol and recommendations for the site demonstration. Site 70 was proposed by Mr. Paul Barker, WR-ALC/EMQ, as an appropriate weathered TPH site for the demonstration program. Phase I activities also included the collection of historical, geological, geographical, and existing analytical data for the selected site to use in the preparation of a sampling plan during Phase II.

The demonstration program will utilize data collected during previous site investigations and remedial activities at UST Sites 70 and 72. The scope of work for the Phase II effort includes development of a sampling plan, installation of soil borings at selected locations based on existing site data, collection of soil samples, analysis of samples, and an analysis of the data, including a risk assessment. Soil samples will be collected from the zone of maximum TPH contamination to the edge of the zone of contamination for chemical analyses. OpTech personnel will collect soil and groundwater samples. Lancaster Labs will perform conventional TPH in addition to fractionation analyses using the Direct Method developed by Shell Developmental Company.

Based on previous site investigative work, split spoon samples will be collected at discreet points in the zone of contamination for TPH fractionation analysis. Correlation between the analytical results from the fractionation method and the conventional TPH analysis (modified EPA 8015) will be established. Good correlation would allow risk-based cleanup levels to be developed using the Working Group approach based on a limited number of fractionated samples. The risk assessment portion of the Phase II effort will use the ASTM RBCA method to calculate RBSLs for soils.

A1.2 General Investigation Approach

Phase I (data gathering) of the demonstration program was undertaken in April, 1998, with a visit to Robins AFB, Georgia. The Phase I effort included discussions with base personnel and State regulatory agents regarding the Working Group approach and the objectives of the demonstration project. This included briefing those representatives of the regulatory community

involved in the evaluation of new analytical techniques and methodologies. The Phase II field investigation at the selected UST site will incorporate the installation of soil borings. Soil samples will be collected at the level of maximum contamination and near the vertical limits of contamination over the length of the contaminant plume. These field investigation data will be used to fulfill the objectives of the demonstration project and perform the risk assessment.

A1.3 Work Plan Structure

A1.3.1 Work Plan Outline

The Work Plan provides a description of the activities for the investigation and is organized into the following sections:

A1.0 Introduction defines the purpose and scope of the investigation.

A2.0 Project Management Approach provides a description of the project management plan for the execution of this project.

A3.0 Facility Background Information provides background information on the environmental setting of the base and the selected UST site.

A4.0 Environmental Setting provides information on physical characteristics that apply to the base and the selected site(s).

A5.0 Field Investigative Procedures describe the procedures used for each applicable investigative method and field screening technique for each site.

A6.0 Risk Based Corrective Action provides a brief description of the ASTM RBCA framework which will be applied to the TPH fractionation data.

A7.0 References

A2.0 PROJECT MANAGEMENT APPROACH

The successful execution of this project requires a strong, qualified project team. Accordingly, the contractor will provide an experienced team of professionals who have prior field investigation experience. This effort will be performed in conjunction with an investigation program on the Robins AFB UST sites by the UST Remediation Program contractor for Robins AFB, and will be coordinated by Mr. Paul Barker, WR-ALC/EMQ.

A2.1 Project Management Organization

The project will be managed and executed by personnel selected by the contractor who will ensure that the objectives of the field investigation are met. Analytical services support will be provided by firms experienced in performing their specific assigned tasks, and which possess the

required permits, licenses, and accreditation necessary to work in Georgia. The project management organization is shown in Figure A-1. The contractor project team will include the following key professionals:

The Program Manager will be responsible for the overall execution of this project and for maintaining an open line of communication with the AFRL/HEST Program Manager.

The Project Manager will directly supervise the project team, provide technical direction and technical interface with the AFRL/HEST Program Manager, direct field operations, and coordinate contractor and subcontractor support.

The Site Manager will directly supervise the field investigation project team and provide technical direction and technical interface with the Project Manager.

The Manager of Quality Assurance/Quality Control (QA/QC) will be responsible for developing standardized quality assurance procedures for this project, and for ensuring that effective procedures and controls are implemented to achieve a high level of project accuracy.

Project Scientific Personnel will include qualified geologists, engineers, and other specialties (i.e., technical advisor and RBCA specialist) required to conduct the field investigation.

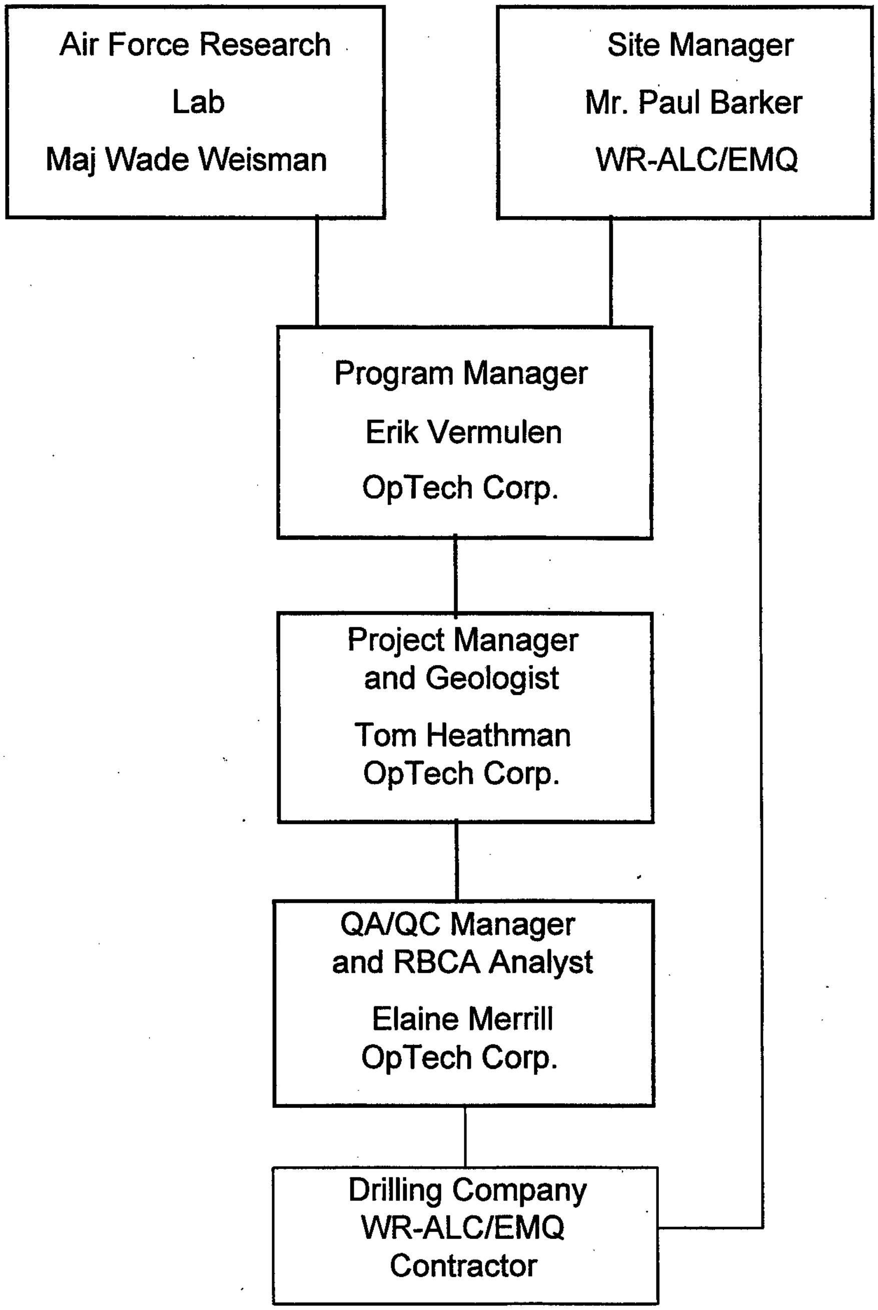


Figure A-1 Project Management Organization

A2.2 Project Procedures

An open line of communication will be maintained between the Project Manager and the project team to ensure that all project objectives are met. Verifiable sample custody will be an integral part of the fieldwork. Samples will be properly collected and identified. All sampling activities will be carried out in accordance with the OpTech Quality Assurance Program Plan (QAPP). The overall field investigation will be executed within the time frame of the project schedule. All

information pertinent to field observations and sampling will be indelibly recorded daily in bound field notebooks, maintained by both the WR-ALC/EMQ drilling contractor and OpTech. A copy of each daily log entry from field personnel will be placed in the project file. The field logs will, at a minimum, contain the following information for this investigation:

- Date, time, and type of activity;
- Names and affiliations of persons collecting samples;
- Weather conditions;
- Sampling and preservation procedures;
- Sampling locations, depth, and conditions;
- Time of sampling and sample description;
- Remarks; and
- Signature of author.

A2.3 Quality Management

The OpTech personnel gathering samples will be responsible for ensuring that all quality control (QC) procedures are followed. Immediate corrective actions will be taken at any time they are deemed necessary. All quality control procedures will be directed in accordance with QAPP.

A2.4 Subcontract Management

The contractor is responsible for the cost, schedule, and quality of all work performed under this contract delivery order, including the work of subcontractor, Lancaster Labs. Lancaster Labs is the OpTech subcontractor for analytical services (the TPH fractionation analysis). The contractor Project Manager will maintain oversight of the subcontractor completion of specified tasks with respect to technical performance, quality, and adherence to cost and schedule. All field activities will be in compliance with the QAPP and the site Health and Safety Plan for the field investigations.

A2.5 Drilling Subcontractor Management

WR-ALC/EMQ will provide direction and management to the drilling subcontractor selected to support sample collection. The drilling subcontractor will be responsible for operations under operating procedures approved by Robins AFB, they will obtain all necessary drilling permits, assure avoidance of underground utilities and interface with OpTech field personnel to help achieve the objectives of this study. Copies of field logs will be provided to OpTech for the report.

A3.0 FACILITY BACKGROUND INFORMATION

A3.1 Facility Description

Robins AFB is located in central Georgia approximately 17 miles south of Macon and immediately east of the city of Warner Robins. The base encompasses an area of approximately 9 square

miles and occupies a large portion of the Ocmulgee River Terrace and floodplain of northeastern Houston County (HAZWRAP, 1997). Robins AFB is home to the 19th Refueling Group, 93rd Air Control Wing (Joint-Stars), and the Warner Robins Air Logistics Center.

A3.2 Site Description

Robins AFB is located in the Fall Line Hills and Ocmulgee River Valley subdivision of the Coastal Plain Physiographic Province. Most of Robins AFB lies within the Ocmulgee River Valley, which is characterized by nearly flat to gently sloping terraces and swampy, bottom land floodplains on the west side of the Ocmulgee River. The floodplain and terrace system on the west side of the river locally ranges between one and three miles in width. UST Site 70 is located on filled land within the Ocmulgee River floodplain. Total relief within 1 mile of the site is less than 20 ft.

Site 70 is located in the 19th Air Refueling Group and 93rd Air Control Wing area of the northeastern portion of Robins AFB. UST Site 70 serves as a large aircraft refueling/defueling hydrant system providing ground support to the 19th Air Refueling Group and the 93rd Air Control Wing. The combined operational area for the refueling group and the Air Control Wing encompasses approximately 31 acres situated adjacent to the north aircraft parking apron.

The aircraft refueling/defueling hydrant system at Site 70 consists of a small storage building (Building 28), a pumphouse/control room (Building 2070), six 50,000 gallon steel USTs containing jet fuel, a 2,000 gallon steel UST containing waste fuel, a 400 gallon UST containing water, and approximately 5200 feet of 4 to 6-inch diameter steel lines supplying 6 hydrants located on the adjacent parking apron. The USTs and associated lines were originally installed in 1958. The tanks were used for storage of JP-4 jet aircraft fuel until June 1994 and JP-8 jet aircraft fuel since June 1994.

A3.3 Previous Investigations

Numerous maintenance and investigatory actions have been undertaken at Site 70. Tables A-3 and A-4 in the Attachment provide a chronological summary of significant environmental events at the site as well as reports and/or publications resulting from those events, respectively. The following information focuses on those discoveries, investigations, and actions pertinent to the contamination at Site 70.

Fourteen 4-inch diameter vapor monitoring wells were installed in the tankfield of UST Site 70 during a base-wide UST environmental upgrade program in 1992. The wells were approximately 12 feet deep and extended into the shallow groundwater at the site. Two additional 2-inch diameter vapor monitoring wells were installed at each site in September, 1993. EA Engineering, Science, and Technology detected free product in 10 of the 14 vapor monitoring wells on 16 September 1993. EA removed approximately 16 gallons of free product from the tankfield vapor monitoring wells using a combination of petroleum-absorbent pads and manual bailing.

Electrical contractors excavating a pit for new underground lines encountered free product on groundwater on 28 October 1993. The excavation was approximately 35 to 40 feet south-southwest of the tankfield at UST Site 70. Approximately 20 gallons of liquid hydrocarbons were removed from the excavation using a waste pumping truck.

As a result of the discovery of free product, USTs 5 and 6 at Site 70 were tested for tightness by Tanknology, using precision vacuum pressure testing. Results indicated an air leak at one of the exterior components of the UST system. The leak could not be isolated and sealed; therefore both USTs failed the test. The other USTs at the site were not tested using this method because Air Force personnel believed the same type of leak would show up in the other USTs.

An Initial Site Characterization in the area of Site 70 was undertaken in late 1993 by EA in response to the detection of free product in the ten vapor monitoring wells. The purpose of the initial characterization was to determine if soil or groundwater was impacted by petroleum, to identify private and public water supply wells within 0.5 and 3.0 miles, respectively, of the site, to report results of free product recovery activities up to that date, and to describe planned contamination assessment activities to be conducted at the site. Following completion of the initial site characterization, EA was retained by the AF to conduct a UST contamination assessment at Site 70. A total of 15 borings were drilled near UST Site 70 during January 1994 for the assessment. Soil samples were taken from each boring at designated intervals for headspace screening with an Organic Vapor Analyzer (OVA). One soil sample from each boring was submitted for analysis by an off-site laboratory. Ten of the borings were completed as monitoring wells and groundwater samples were collected and analyzed. Water levels and free product measurements were taken; free product was recovered using manual and skimmer techniques. The unexpected large aerial extent of the dissolved hydrocarbons and contractual limitations contributed to the incomplete delineation of the dissolved phase plume (see Figure A-2). Therefore, a second phase of investigation was initiated.

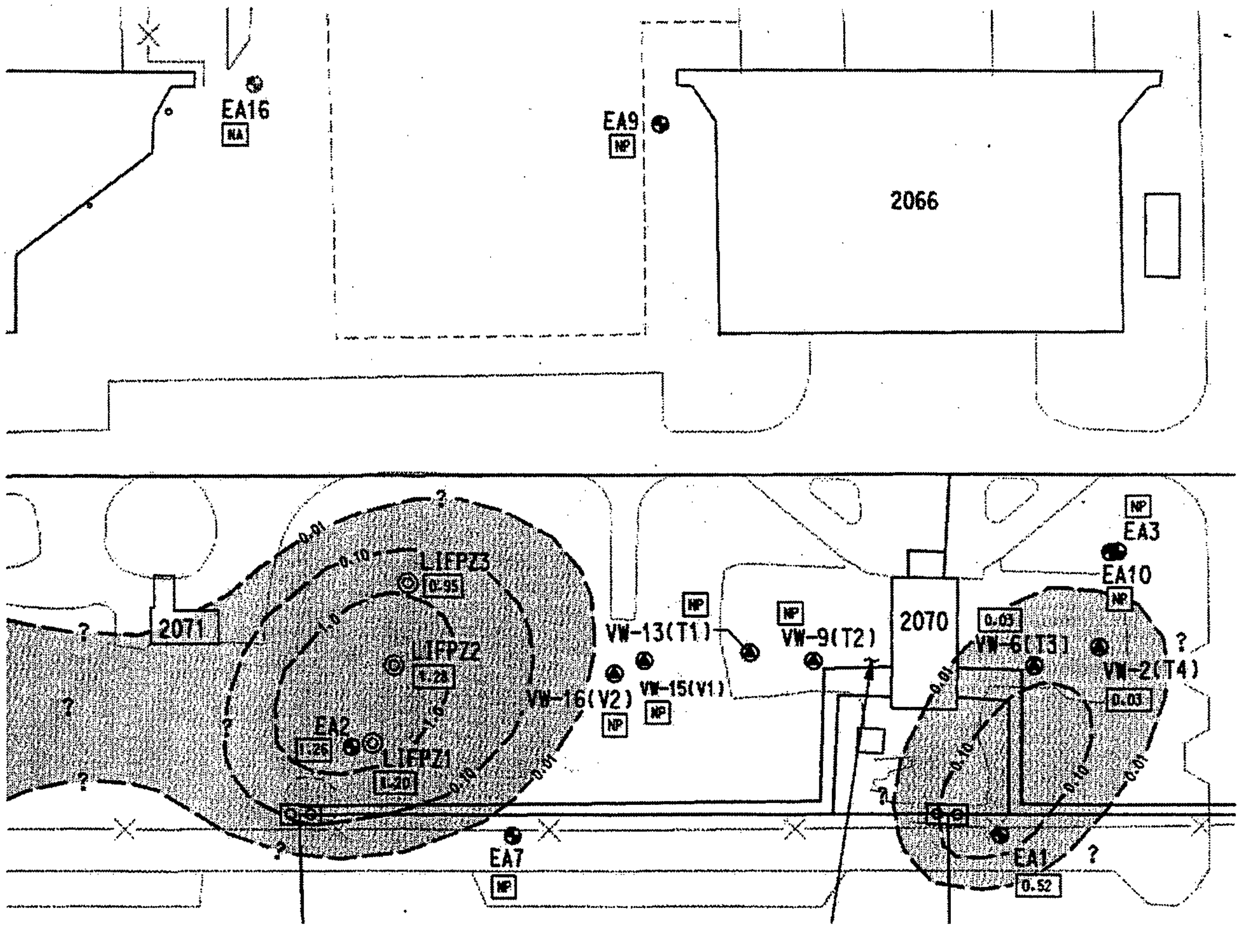


Figure A-2 Location of Monitoring Wells and Thickness of Free Product Prior to Remediation*
(* Adapted from HAZWRAP, 1997)

EA continued the assessment activities at Site 70 and expanded the assessment to include the adjacent UST Site 72. A total of 15 additional borings were installed in August 1994. Thirteen of these borings were completed as monitoring wells and groundwater samples collected for laboratory analysis. Soil samples were screened using OVA headspace analysis and one soil sample per boring was submitted for off-site laboratory analysis. Before the boring program, an active soil vapor survey was conducted at 20 locations using shallow vapor probes and field gas chromatography. This vapor survey proved ineffective in delineating source and/or groundwater contamination. The findings of the site assessment activities indicated a large residual phase petroleum hydrocarbon plume surrounding the tankfield at Site 70 and a large dissolved phase petroleum hydrocarbon plume extending downgradient east and southeast of the site.

The U.S. Army Corps of Engineers, Kansas City Geotechnical Branch demonstrated the Site Characterization and Analysis Penetrometer System (SCAPS) at Site 70 in February 1995. The SCAPS system uses a laser induced fluorescence tool to indicate free product and/or residual contamination thickness and depth. The demonstration was limited to an area around the EA-2 monitoring well. Eighteen push points were installed, of which 16 were logged to develop continuous profiles of shallow stratigraphy and zones of hydrocarbon contamination. The results

of the demonstration showed a 2.5 ft interval from 6 to 8.5 ft below ground surface (BGS) of elevated hydrocarbon fluorescence that correlated well with the maximum free product thickness measured in the nearby monitor well.

In July 1995, Batelle provided some additional site characterization information in conjunction with a short-term field pilot test of the Bioslurper system at Site 709. Three product recovery wells were installed and three soil gas monitoring well clusters were installed. Two soil samples were collected and analyzed for TPH and benzene, toluene, ethylbenzene, and xylene (BTEX) and some geotechnical parameters. A sample of free product was also taken for laboratory analysis.

In October 1996, the Department of Energy Hazardous Waste Remedial Actions Program (HAZWRAP) undertook an investigation of soils and groundwater upgradient and to the east of the known source areas and filled in some data gaps. Seventeen locations were investigated using either the Geoprobe direct push system or using hand augers for shallow temporary piezometer installation. Seven of those locations were upgradient of the source areas of UST Sites 70/72 and eight others were to the east and northeast of the source contamination at UST Sites 70/72. Two locations were used to obtain data closer to the contaminant source. Soil boring logs were completed for each location and soil samples were screened with an OVA in the field. Some of the soil samples were analyzed at an off-site laboratory for petroleum hydrocarbon organics, including gasoline range organics, diesel range organics (DRO), BTEX, methyl tert-butyl ether, and trimethylbenzene, as well as geotechnical parameters. Some sampling points included identification of clay and/or peat layers for delineation of groundwater flow barriers and/or extremely adsorptive units. Groundwater conditions were investigated at multiple piezometers and data on fuel-related compounds and natural attenuation indicators were collected. The investigation included contaminant transport in groundwater and natural attenuation modeling for the site.

A3.4 Remedial Actions Undertaken

As stated in Section 3.3 of this report, remedial actions to remove free product petroleum hydrocarbons were undertaken in September 1993 at the vapor monitoring wells and in October 1993 at the utility excavation. Remedial actions at the vapor monitoring wells included manual bailing of free product and clean up with petroleum-adsorbent pads. Approximately 16 gallons of free product was removed during that action. The remedial action at the utility excavation south-southwest of the tankfield at UST Site 70 included removal using a vacuum waste pumping truck. Approximately 20 gallons of liquid hydrocarbons were removed from the excavation.

In March 1994, a DPI Petro-belt hydrocarbon-only belt skimmer was installed on monitoring well EA-2 to recover the free product (see Figure A-2). Manual free product recovery methods were also initiated at monitoring well EA-1 at that time. A total of 1,796 gallons of liquid petroleum hydrocarbons had been collected at Site 70 through July 1995 using these methods. Following initial field testing in July 1995, the Batelle Bioslurper system began running full time at monitoring well EA-2 in late spring of 1996. During continuous operation, free product was recovered at an estimated 8 to 12 gallons per day. Approximately 3,400 gallons of free product were recovered through the Bioslurper. The Bioslurper was removed in October 1997 when the free product layer had been removed in the vicinity of monitoring well EA-2.

To date, removal of petroleum contaminated soils has been limited to those soils removed that were associated with excavations for repairs to lateral control pits and disposal of drill and auger cuttings. No USTs have been removed from Site 70; therefore significant amounts of soils at the UST site have not been removed.

A3.5 Source of Contamination

The source of free product and residual contamination in soils at the UST Site 70 appears to result from some combination of historical leaks, spills, and overfills related to the jet fuel storage and distributions system at the site. A leak was documented in lateral control pit #3 at Site 70 in 1995. Soil contamination and free product occur relatively near the lateral control pit; suggesting that it may represent a significant source for this nearby contamination. Free product and soil contamination detected in vapor wells and borings at and around the Site 70 tankfield appear to have occurred from surface spills and/or overfills there. Free product has also been found up to 150 feet away from the tankfield, including several areas near the valve junction boxes just off the east end of the concrete tarmac. These junction boxes may also have been significant sources over time.

Environmental staff also report that various fuel spills and overfills have occurred on the tarmac associated with the fueling of aircraft. These spills were washed over the edge of the concrete tarmac and may have also been significant sources of contamination.

A4.0 ENVIRONMENTAL SETTING

A4.1 Meteorology

The climate at Robins AFB is characterized by long, hot summers and comparatively mild winters. During the summer months, the average daily temperature ranges from approximately 71 to 92°F. During the winter months, by comparison, the average daily temperatures range from approximately 35 to 57°F. The average annual precipitation for the region is 44.7 inches. Precipitation is evenly spread over the winter, spring, and summer months. The prevailing wind direction is west-northwest, but northerly and southwesterly winds occur with nearly equal frequency from December to March. Average monthly wind speed varies from 6 to 12 miles per hour.

A4.2 Geology

Bedrock underlying Robins AFB is composed of sedimentary strata. The upper most formation on the eastern part of the base is Recent/Quaternary Alluvium associated with fluvial deposits of the Ocmulgee River and its floodplain. This is underlain by three formations of Late Cretaceous age: the Providence Formation, the Cusseta Formation, and the Eutaw-Blufftown Formations. The alluvium consists of interbedded layers of sand and gravely/clayey sand, clays of varying color and consistency, and organic clays and peats. The alluvium is a relatively thin veneer of sediments from 10 to 30 feet deep that is often indistinguishable from the underlying Providence Formation.

The Providence Formation consists of fine to coarse sand with lenses of kaolinitic clay. The underlying Cusseta Formation (usually estimated to be 30-60 feet thick) consists of clay and sandy clay with interlayered sand. The Blufftown Formation consists of medium to coarse sand and interbedded clay.

A4.3 Soils

The surface soils of Robins AFB are predominantly residual or alluvial. The soils in the area of Site 70 are fill material overlying alluvium. Filling and grading activities over the years have disturbed or obliterated the natural soils. The fill material ranges from 5 to 10 feet thick and is described as reddish clayey-sand with large gravel. The underlying alluvium is described as brown clayey sand grading to fine to medium grained sand with abundant interbedded organic clay and peat layers.

A4.4 Hydrogeology

In the eastern part of Robins AFB (in the area of Site 70), groundwater is encountered at 3 to 10 feet below ground surface in the fill material. The alluvium of the Ocmulgee floodplain carries some groundwater and is considered a surface aquifer in the area. The underlying Providence Formation is also considered an aquifer. The combined alluvium and Providence aquifers are about 130 to 150 feet thick in the eastern part of the base. The underlying Cusseta Clay is considered an aquitard (lower confining layer) of approximately 30 to 40 feet thick. No active on-base drinking water supply wells are screened within the alluvial/Upper Providence aquifers. Groundwater flow in the alluvial/Upper Providence aquifer in the vicinity of Site 70 appears to be to the east; however, the direction of flow may be influenced by seasonal flows in the alluvium and preferential pathways formed by underground utilities.

A4.5 Surface Water Drainage Routes for the Base

The aircraft refueling/defueling systems at UST Site 70 are situated at an elevation of approximately 260 feet above mean sea level and are characterized by very low relief (± 1 to 2 feet) across the site. The site is located within a peninsular area created by elevated fill that is 8 to 10 feet higher than the surrounding swamps of the Ocmulgee River floodplain. The nearest natural stream is the Ocmulgee River, which flows to the southeast approximately 4,200 feet north-northeast of Site 70. The swamplands surround the peninsular fill area on the north, east, and southeast sides and are flooded periodically during higher stages of the Ocmulgee River. Site stormwater runoff is controlled by storm sewer grating and piping and is conveyed to the north-northwest to a stormwater retention pond. Water in the pond is slowed by weirs before discharging to wetland areas to the east and northeast.

A4.6 Critical Environments

The immediate vicinity of UST Site 70 is industrial. However, preferential pathways created by underground utilities could potentially transfer contaminants to nearby surface water bodies such

as the stormwater collection pond near the northeastern margin of the site. Critical environments that may be impacted by the contaminants include the swamplands of the Ocmulgee River floodplain and the Ocmulgee River.

A5.0 INVESTIGATIVE APPROACH

A5.1 Work Plan and Data Quality Objectives

The objective of the Work Plan is to ensure that all field activities meet the requirements of Maj Wade Weisman, Air Force Research Laboratories. Performance of the effort will be conducted in coordination with Mr. Paul Barker, WR-ALC/EMQ; Mr. Kevin Long, WR-ALC/EMQ; Ms. Chifeng Gu, Georgia Environmental Protection Department; and OpTech. As stated earlier, the main objectives of the sampling program are to acquire data of sufficient quality to:

1. Demonstrate that the TPH fractionation analytical method provides data that is of quality required to conduct a risk assessment;
2. Evaluate correlation between conventional method results and the fractionation results;
3. Apply the Working Group approach within the ASTM RBCA framework to estimate risk to human health and develop risk-based soil screening levels;
4. Develop soil screening levels for residual contamination in an area where free product has been removed; and,
5. Compare soil screening levels developed from the fractions present to those developed by the Georgia Environmental Protection Department (EPD) criteria.

These objectives require quantification of the extent of contamination, the magnitude of contamination, and the migration of any contaminants from the sites. Previous soil and groundwater investigation reports, gathered during the Phase I site visit, were evaluated to establish the general areas where samples should be collected. In addition, a portable gas chromatograph (GC) Photo Ionizing Detector (PID) will be used in the field for screening the zones of contamination to be sampled.

Data quality objectives (DQOs) for the project require fixed-base laboratory data. Fixed-base laboratory DQOs will meet definitive data quality requirements as defined in "Data Quality Objectives Process for Superfund, Interim Final Guidance "(EPA, 1993), and guidance for planning for data collection in support of environmental decision making using the data quality objectives process (EPA, 1994). Fixed-base laboratory analytical methods, QC, and data reporting requirements include Contract Laboratory Program type QC and documentation, as well as summary forms and supporting documentation for definitive level data as required by EPA/540/G-93/071 (EPA, 1993). OpTech's field quality control on the samples will consist of collecting one duplicate per ten samples, one trip blank per container, and one equipment rinseate blank per day of sampling.

A5.2 General Approach for Phase II: Sampling Strategy and Rationale

A5.2.1 Soil Sampling

Soil samples will be collected through split-spoon sampling using an auger rig. Upon retrieval of the split spoon sampler, a representative sample will be composited quickly in a stainless steel bowl and divided into laboratory-supplied sample jars with Teflon lined lids labeled to indicate location, date, and depth interval. EPA Method 8035 for collection of volatile organic carbons will be followed. The sample jars will be filled allowing minimum headspace and then placed on ice in a cooler chest for subsequent laboratory analysis. An effort will be made to minimize potential off-gassing of volatiles during drilling and sampling. All samples will be shipped to the laboratory via FedEx within 24 hours of sampling. No samples will be kept on site overnight.

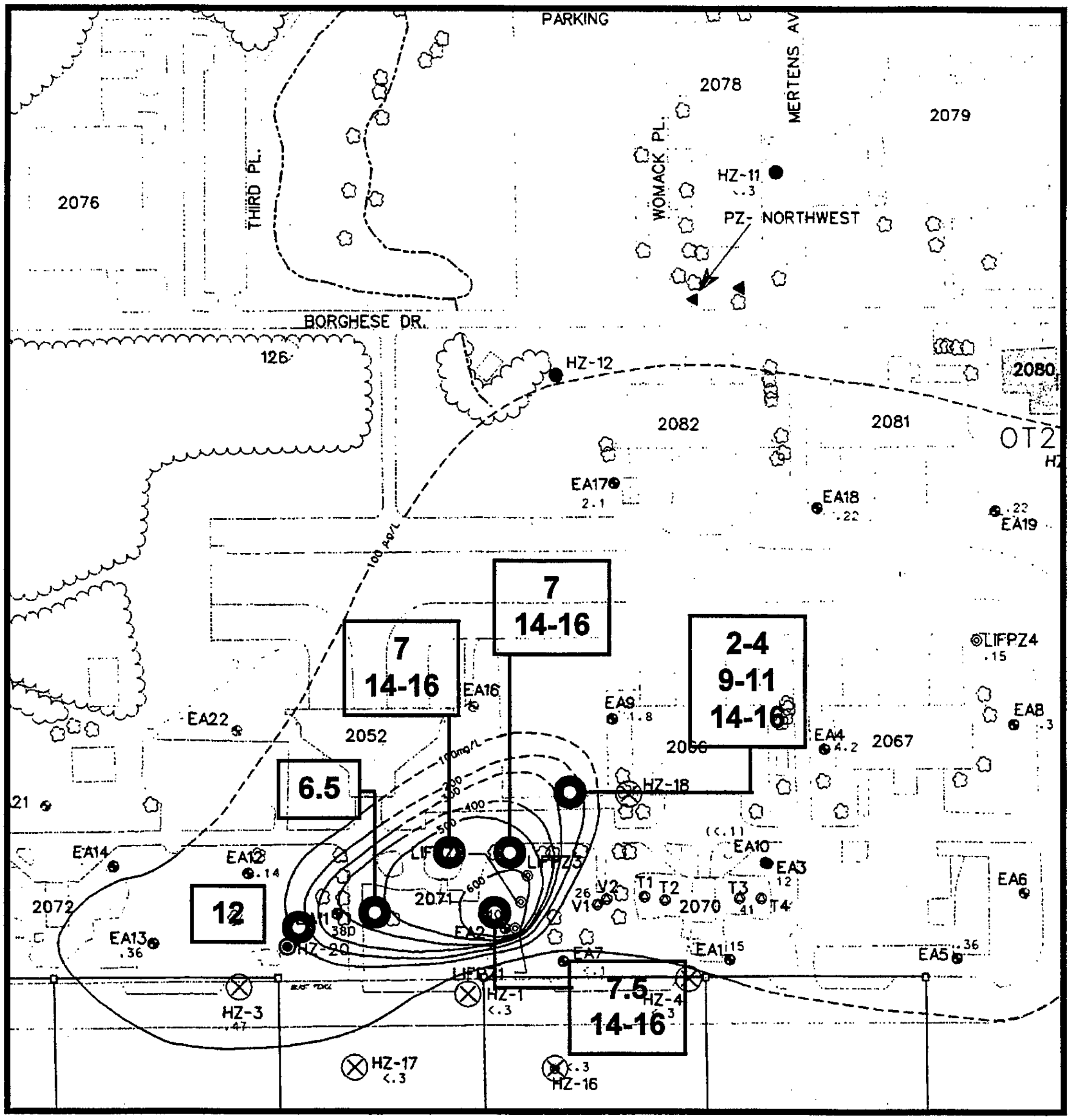
The initial sample locations for the soil borings are chosen based on the best available data collected during the Phase I data gathering visit. The goal of the sampling effort is to collect from a point of maximum contamination and downgradient in and around the area of free product removal. Samples will be taken from a total of eleven points within six soil borings. The soil samples will be analyzed by the Direct Method for TPH fractionation, 8020 for BTEX, and 8015M for conventional TPH. It is anticipated that any variation of the degree of contamination within the three samples from the composite will be minimal. One set of duplicates for every ten samples will also be submitted.

A5.3 Site-Specific Investigation Activities

A5.3.1 Soil Boring Installation and Subsurface Sampling

Sampling activities are expected to take place in mid June 1998. Drilling services will be provided by the WR-ALC/EMQ contractor for investigations, and OpTech field personnel will be provided with appropriate personal safety equipment and safety training. In accordance with the Site Health and Safety Plan, work at Site 70 will begin at Level D personal protection with frequent monitoring to assure that Level D is appropriate. Protection Level C equipment and trained personnel will be available so that work can proceed at Level C, if required. All contractor and subcontractor personnel will adhere to the Site Health and Safety Plan requirements. All work will be performed in a manner consistent with State and Federal laws and regulations.

Soil borings will be drilled near monitoring well EA-2 within the area of DRO contamination (see Figure A-3). Maximum TPH contamination was detected here at 6 to 7.5 feet BGS with contamination down to 16 feet BGS. Target depth will begin at approximately 2 feet and run to 16 feet based on previously detected levels of TPH. Based upon the volatile hydrocarbon profile from PID readings and visible soil characteristics, an on-site geologist will determine whether composited samples will be taken.



Legend

Proposed Soil Boring Location

DRO Isopleths (mg/L) in upper aquifer (Dashed where unknown or inferred)

2-4 7.5 12	Depth (ft BGS) to Zones of Interest in Proposed Soil Borings

Figure A-3 Proposed Locations of Demonstration Project Soil Borings*
(* Adapted from HAZWRAP, 1997)

The zone of highest contamination and the bottom of the measurable contamination are targeted for sampling (see Table A-1). These sampling depths will provide information on fractionation of the TPH contamination with depth. Because existing data on the site indicate that lateral migration of contamination was predominant due to the shallow groundwater level, the borehole locations proposed are located to investigate variations in the distribution and composition of TPH fractions over the length of the plume. Collection of soil samples at depth (>10 feet BGS) will provide information on TPH fractions that might migrate vertically preferentially over lateral migration.

TABLE A-1 PROPOSED SAMPLE BORINGS FOR SITE 70

Boring Number	Sample Intervals	Sample Objective
DSB1	12 ft BGS	Soil contamination neat Lateral Pit #1
DSB2	6.5 ft BGS	Free product residual at groundwater surface
DSB3	7, 14-16 ft BGS	Free product residual and lower soil contamination
DSB4	7.5, 14-16 ft BGS	Free product residual and lower soil contamination
DSB5	7, 14-16 ft BGS	Free product residual and lower soil contamination
DSB6	2-4, 9-11, 14-16 ft BGS	Near surface contamination, mid and lower soil contamination near Building 2066

An effort to obtain additional geotechnical analyses from this sampling effort does not appear to be necessary. However, OpTech will have samples analyzed for moisture content. Extensive geotechnical data from the site was collected by the Air Force and is presented in the Corrective Action Plan (CAP) Phase B Report (HAZWRAP, 1997). Data available include permeability, grain size distribution, porosity, total organic carbon, and bulk density.

A5.4 Analytical Methods

As mentioned earlier, one objective of the demonstration will be to measure the correlation between the conventional TPH method and the fractionation analysis (the Direct Method) specified by the Working Group. Former spills and leaks of JP-4 are the major source of contamination at UST Site 70; therefore, a conventional method that optimizes analysis of mid to heavy distillates, such as SW-846 8015A, *Nonhalogenated Volatile Organics by Gas Chromatography/Flame Ionization Detector*, or modifications thereof, is appropriate.

The Direct Method, originally developed by Shell Development Company, separates hydrocarbons into different carbon ranges using a GC. The hydrocarbons are then fractionated into aliphatic and aromatic hydrocarbons using column chromatography. This combination of the column chromatography and gas chromatography is called hydrocarbon speciation. Output from the analyses will be reported as aliphatic and aromatic fractions of the petroleum hydrocarbons present in the sample (see Figure A-4).

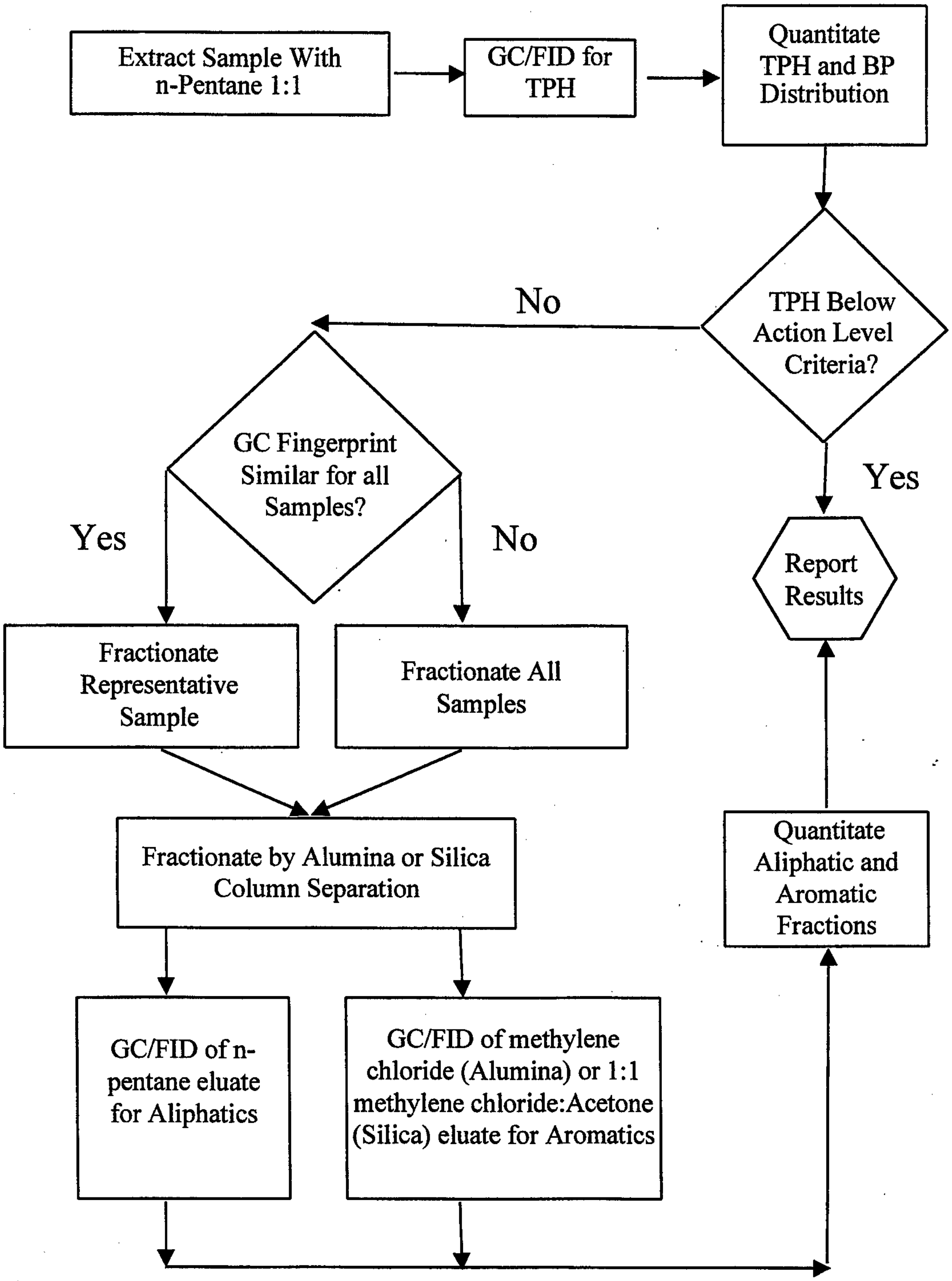


Figure A-4 TPH Criteria Working Group Direct Method

Following separation of the aromatics and aliphatics on the alumina or silica gel column, the two separate extracts are analyzed by GC with flame ionization detector. The volatiles range analysis can report the BTEX "fractions" or components. However, in cases where lighter constituents (i.e., <n-C9) are observed, GC/mass spectrometry (EPA Method 8240 or 8260) should be performed to quantify the BTEX with greater accuracy. Also this approach should not take the place of determination of standard polynuclear aromatic hydrocarbons (polycyclic aromatic hydrocarbons by 8270), which will not be analyzed for at this site. Instead the hydrocarbon speciation is a tool to determine the non-carcinogenic risk present by hydrocarbons in a soil or water sample in addition to the risk posed by any of the target compounds in these standard EPA methods.

Fixed-base laboratory analysis will meet definitive level data requirements as defined by "Data Quality Objectives Process for Superfund, Interim Final Guidance" (EPA, 1993). All fixed-base laboratory analysis will require approximately 21 days turnaround for data package deliverables.

A5.4.1 Hydrocarbon Ranges

The ranges described in these methods are typically defined in equivalent carbon (EC) numbers. Normal hydrocarbons such as hexane (C6), decane (C10), hexadecane (C16), and heneicosane (C21) are used to define the ranges. The responses for any hydrocarbons that elute between the marker hydrocarbons are summed together to create a total concentration of that range. A typical range could then be defined as the hydrocarbons eluting after hexadecane (C16) to heneicosane (C21) which is listed as EC > 16-21 or >C16 - C21.

The Working Group has developed different fractions to be used in the RBCA analysis over the C5 to C35 range. These are listed in Table A-2. This range covers the most significant hydrocarbons for many hydrocarbon distillates, from gasoline to Bunker C oil and lubricating oils. These ranges are normalized to EC numbers based on the normal alkanes.

TABLE A-2 WORKING GROUP AROMATIC AND ALIPHATIC FRACTIONS

Aromatic Fraction	Aliphatic Fraction
EC > 5-7 (benzene)	EC > 5-7
EC > 7-8 (toluene)	EC > 7-8
EC > 8-10	EC > 8-10
EC > 10-12	EC > 10-12
EC > 12-16	EC > 12-16
EC > 16-21	EC > 16-21
EC > 21-35	EC > 21-35

A5.5 Deviations from the Work Plan

If during the execution of the demonstration program, it is identified that changes to the Work Plan are necessary to enhance the objective of the project, the OpTech program manager will verbally contact the Armstrong Laboratory program manager with the recommended changes. The recommendations will be followed up with written documentation with the required changes.

A6.0 RISK BASED CORRECTIVE ACTION METHOD

The RBCA process as described in the ASTM standard recognizes the diverse physical and chemical characteristics of sites with petroleum releases. It uses a tiered approach where corrective action activities are tailored to site-specific conditions and risks. The decision process integrates risk and exposure assessment practices, as suggested by the United States Environmental Protection Agency (EPA), with site assessment activities and remedial measure selection to ensure that the chosen action is protective of human health and the environment.

The Working Group 13 fractions are divided based on order of magnitude differences in fate and transport characteristics, such as water solubility and vapor pressure. Specific fate and transport values are assigned to each of the 13 fractions. Hence, the fate and transport models within the ASTM framework result in higher levels of potential exposure for lighter aromatics, which have a greater tendency to leach into groundwater or volatilize to the air pathways. Likewise, lighter aliphatics which tend to partition readily into the air may pose greater exposure potential than heavier fractions. The 13 fractions have been assigned specific toxicity values or reference doses (RfDs) based on best available toxicity data on indicator compounds within each fraction. The RfDs only address the non-carcinogenic compounds represented in the TPH mixture. Carcinogens are always evaluated separately since their risk tends to drive cleanup. The risk characterization approach assumes additivity of the hazard quotients resulting from each fraction. RBSLs are calculated assuming a target hazard index of 1 for the entire mixture (a total of hazard quotients for all the fractions). This means that each fraction is allocated a portion of the target risk level, with the sum of the hazard quotients from all fractions equal to a hazard index of 1 for the mixture. RBSLs and a draft risk analysis report will be completed within four to five weeks of receiving the analytical results.

A7.0 REFERENCES

ASTM, 1995. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites. ASTM Standard E 1739-95.

EPA, 1993. Data Quality Objectives Process for Superfund, Interim Final Guidance. Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C. OSWER 9355.9-01, EPA 540/R-93/071, PB94-963203.

EPA, 1994. Guidance for the Data Quality Objectives Process. EPA QA/G-4. Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C. EPA/600/R-96/055.

HAZWRAP, February, 1997. Draft Corrective Action Plan- Part B for Underground Storage Tank Sites 70 and 72 at Robins AFB. Hazardous Waste Remedial Actions Program, Department of Energy, Oak Ridge, Tennessee.

A8.0 ATTACHMENT: SUMMARY OF SIGNIFICANT ENVIRONMENTAL EVENTS AT UST SITES 70/72, ROBINS AFB, GEORGIA

TABLE A-3 CHRONOLOGICAL SUMMARY OF SIGNIFICANT ENVIRONMENTAL EVENTS AT UST SITE 70/72 INCLUDING TIGHTNESS TESTS, RELEASE DETECTION, AND RESPONSES, AND SITE INVESTIGATIONS

Time Period	Activity/Event	Agency/ Company	Comments/ Conclusions	Code
~1958 to 9/91	Tank cleaning every 5 years.	-		
~1958 to mid-80's	Hydrostatic testing of tank hydrant supply system, ~ 5 yr intervals.	-		T
1958-present	Undocumented releases from overfills, surface spills, and leaks in piping.	-	Contribution to current extent of free product and soils contamination is unclear.	R
Sep. 1990	UST tightness testing.	Fitzgerald & Associates	Ainley method shows no leaks (no 3rd party certification).	T
Mar. 1991	Leak at lateral control pit # 1 (southernmost) at Site 72.	USAF	Reported to GA EPD, leak repaired.	R
Mar. 1991	Ten soil borings, soils analysis for TPH, removal of contaminated soils; following leak reported March 5, 1991 at lateral control pit #1 (Site 72).	USAF/Preston Testing & Engineering		R, I
Sep. 1993	Installation of 32 vapor monitoring wells in tankfields at Sites 70/72; Background Characterization Report for UST Sites generated.	EA Engineering	High vapor concentrations at 2072 tankfield, free product discovered in 2070 tankfield and reported to EPD. Report date: Dec. 1993.	T, R
Oct. 1993	Free product found on groundwater in open construction excavation 35-40 ft SSW of Site 70 tankfield.	Electrical contractors	Free product pumped on 2 consecutive days before backfilling excavation; approximately 20 gallons recovered.	R
1993	Initial site characterization and Report for UST 70 Site. Gauging and free product recovery from vapor monitoring wells.	EA Engineering	Report date: 1993.	I
Jan. 1994	Two USTs (5&6) at Site 70 leak tested by precision vacuum pressure testing.	Tanknology Corp. International	Two tanks fail test (other USTs not tested).	T

Time Period	Activity/Event	Agency/ Company	Comments/ Conclusions	Code
Jan. - Apr. 1994	Initial contamination assessment (Phase I) and Contamination Assessment Report for UST 70 Site. Initial characterization of soils and groundwater contamination, free product extent/recovery, and slug tests.	EA Engineering	UST Site 70 Contaminant Assessment Report date: June, 1994.	I
Mar. - Apr. 1994	Tank testing by AZI of 6 USTs and all piping at Site 70 & piping between Sites 70&72 and some lateral lines in aircraft parking area.	Arizona Instrument Corp.	Results show USTs and piping are not leaking (3rd party certification).	T
Jun. - Jul. 1994	"Tracer Tight" testing of 70/72 pipeline & UST area.	Arizona Instrument Corp.	Results show pipeline "tight" - no tracer detections at UST sites, but high vapor concentration detected at 2070 UST site (indicates old spills).	T
Jul. - Oct. 1994	Contamination assessment (Phase 111) expanded to include Sites 70 and 72, and Contamination Assessment Report. Further characterization of soils and groundwater contamination, free product extent/recovery, and slug tests.	EA Engineering	UST 70/72 CAR date: Nov, 1994.	I
Sep. 1994	'Background Site Characterization' for all UST's with monitoring wells.	EA Engineering	Free product detected in 10 of 14 wells at site 70.	T, R
Feb. 1995	JP-8 leak at lateral pit #3 (northernmost pit) of Site 70 system; testing of cathodic protection at all 6 lateral control pits.	USAF	Corrosion found to 12 ft out at lateral control pit #3, piping replacement (12 ft); testing reveals severe galvanic corrosion 12 ft out from all 6 lateral control pits.	R
July 1995	Bioslurper pilot testing. Installation of 3 product recovery piezometers, 3 vapor monitoring cluster wells, and SCAPS characterization. Bioslurper product recovery system left in place.	AFCEE/ Battelle	Bioslurper report date: 28 Nov 1995.	I
Mar./Apr. 1995	Spring basewide groundwater sampling, water level and free product measurements; analyses included bio-attenuation parameters, volatiles.	CH2M Hill	Data included in 70/72 CAP-A.	I

Time Period	Activity/Event	Agency/ Company	Comments/ Conclusions	Code
May 1995	Geophex Annual UST release detection monitoring program.	Geophex	Confirms high vapor concentrations at 2070 tankfield and one high vapor concentration at 2072 tankfield.	T
Sep. 1995	Water level and free product measurements during Fall 1995 basewide groundwater sampling event.	Rust Environmental	No groundwater sampling performed during this event.	I
May/June 1996	Spring basewide groundwater sampling, water level and free product measurements; included bio-attenuation indicator analyses and volatile results.	Rust Environmental	Lab results summary included in Basewide Sampling Report.	I
Sep. 1996	Geophex annual UST release detection monitoring program.	Geophex	Reaffirms high vapor concentrations at 2070 tankfield and two high vapor concentrations at 2072 tankfield.	T
Oct. 1996	Supplemental/upgradient investigation; additional data gaps filled – soil and groundwater sampling & analysis, water level and free product measurements, analysis of geotechnical and natural attenuation parameters.	HAZWRAP	Area under concrete tarmac upgradient of known sources investigated.	I
Nov. 1996	Corrective Action Plan – Part A completed and submitted to GA EPD.	HAZWRAP	Awaiting EPD comments; work on-going to produce CAP-B.	I

Notes: T = UST/line tightness testing or leak detection test; R = detection of release; I = investigation (Source: HAZWRAP 1997, Draft Corrective Action Plan- Part B for Underground Storage Tank Sites 70 and 72 at Robins AFB. Hazardous Waste Remedial Actions Program, Department of Energy, Oak Ridge, Tennessee, February 1997.)

TABLE A-4 REPORTS/PUBLICATIONS GENERATED BY ROBINS AFB SITE INVESTIGATIONS INVOLVING UST SITE 70172

Author	Publication	Date
Air Force Center for Environmental Excellence Technology Transfer Division	Site-specific Tech. Report for Bioslurper Testing at Sites UST 70/72 and 55010, Robins AFB, GA.	1991
EA Engineering, Science, and Technology	Background Characterization Report for UST Sites, Robins AFB, Houston County, Georgia.	1993
EA Engineering, Science, and Technology	Initial Site Characterization Report for the Aircraft Hydrant System, UST Site #70, Robins AFB, Houston County, Georgia.	1993
EA Engineering, Science, and Technology	Background Characterization Report for UST Sites, Robins AFB, Houston County, Georgia.	1994
EA Engineering, Science, and Technology	Background Characterization Report for UST Sites, Robins AFB, Houston County, Georgia.	1994
EA Engineering, Science, and Technology	Contamination Assessment Report for UST Sites 70 and 72, Robins AFB, Houston County, Georgia	1994
Geophex	Annual Release Detection Monitoring Report for May 1995 at UST Sites, Robins AFB, Houston County, Georgia	1995
Geophex	Annual Release Detection Monitoring Report for May 1995 at UST Sites, Robins AFB, Houston County, Georgia	1996

APPENDIX B SUMMARY INFORMATION ON TRANSPORT IN CONTAMINANT SATURATED SOIL

B1.0 INTRODUCTION

Based on data collected from previous investigations and summarized in the Draft Corrective Action Plan - Part A for Underground Storage Tank Sites 70 and 72 at Robins AFB (HAZWRAP, 1996), a conceptual model was developed for Site 70. The conceptual model was developed in accordance with the U.S. Environmental Protection Agency (EPA) 1996 Soil Screening Guidance: User's Guide and was the basis of the sampling plan outlined in the Field Investigative Work Plan in Appendix A. The site conceptual model includes:

- Vadose zone petroleum contamination from vertical migration of spilled hydrocarbons
- Residual petroleum saturation at the water table surface consisting of non-aqueous phase liquids (NAPLs)
- Vapor emissions from the residual petroleum saturation
- Dissolution of hydrocarbons into the groundwater
- Transport of dissolved phase hydrocarbons in the groundwater
- Potential discharge of groundwater to the nearby swamp lands of the Ocmulgee River bottom

Remedial activities at Site 70 included removal of approximately 5,200 gallons of free product from the groundwater surface over time. These remedial activities were halted when free product was no longer recoverable in the vicinity of the recovery well. Based on this information, it was anticipated in the site conceptual model that petroleum hydrocarbon contamination in and around the area of free product recovery would be at or above the saturation concentration for most effective hydrocarbon fractions. Levels of hydrocarbon contamination at or above the saturation concentration can cause numerous problems when assessing risk for the site.

The Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG or Working Group) approach utilizes the American Society for Testing and Materials (ASTM) Risk Based Corrective Action (RBCA) framework for assessing risk and calculating risk-based screening levels for petroleum hydrocarbon contaminated sites. Assumptions made by the Working Group in using the ASTM RBCA framework include an assumption that no free product (i.e., NAPL) is present. The Working Group's Volume 3 states "Although this report does not specifically address NAPL contamination, this approach is not invalid for sites containing NAPLs. For cases where NAPL is present, the upper limit in concentration at saturation in soil vapor and soil moisture must be considered and models relevant to free-phase products applied" (TPHCWG, 1997).

The conceptual model for Robins Air Force Base (AFB), Georgia, must include transport of NAPLs along the groundwater surface to account for hydrocarbon concentrations at or above saturation in the subsurface soils. The Working Group and RBCA fate and transport models do not account for this transport mechanism; therefore additional models must be identified that will deal with NAPL fate and transport. The output from these models must then be integrated into the ASTM RBCA framework to yield appropriate risk-based screening levels for the site.

This paper examines fate and transport models that are available and are designed to model transport of NAPLs.

B2.0 CHARACTERISTICS OF NON-AQUEOUS PHASE LIQUID CONTAMINATION

NAPL contamination can occur from surface spills, storage tank leaks, and distribution system leaks. In the case of near surface spills or leaks, the NAPL will migrate downward through the unsaturated zone. In an unconfined aquifer, a NAPL less dense than water (i.e., light or LNAPL) will pool above the water-saturated pores of the capillary fringe as an immiscible liquid. As it continues to pool, the LNAPL will also move laterally, slightly displacing the capillary fringe due to changes in capillary and gravitational forces (Chevalier, 1998). NAPLs denser than water will continue to migrate downward until an impenetrable geologic barrier is encountered (Guarnaccia *et al.,* 1997). The focus of this paper is on soils and groundwater contaminated by LNAPLs.

The distribution of the NAPL is a function of fluid properties (density, viscosity, interfacial tension, wetting potential, and variable chemical composition), soil properties (grain size distribution, mineral content, moisture content porosity, hydraulic conductivity, and spatial heterogeneity), and system forcing history (Guarnaccia *et al.*, 1997). The NAPL will partition itself between three different phases: (1) as a gas in the vapor phase, (2) as an adsorbed compound in the solid phase, and (3) as a solute dissolved in water (Ravi and Johnson, 1997). As the hydrocarbon migrates beyond an unsaturated soil, a small amount of the whole hydrocarbon mass will remain attached to these soil particles via capillary forces (Dragun, 1988). Boley and Overcamp (1998) show that infiltration of rainwater into the vadose zone can mobilize these hydrocarbons trapped in pore spaces and displace them downward towards the groundwater. If the source is periodic in nature, then during drying periods, not all the NAPL will drain from the pore space, leaving behind an immobile residual, held in place by capillary forces (Guarnaccia *et al.*, 1997).

Dragun (1988) identifies the capillary fringe as the zone that is in direct contact with the water table and is held immediately above the water table by capillary forces acting against the force of gravity. The distance between the water table and the top of the capillary fringe varies with soil type and pore size. LNAPL will migrate downward in unsaturated soils due to gravity and capillary forces until all the mobile hydrocarbons are transformed into residual saturation, it encounters an impermeable bed, or it reaches the capillary fringe. As the LNAPL enters the capillary fringe, it will bypass the smaller, water filled pores and continue migrating downward through larger pores which do not contain water. Downward migration will end when the LNAPL encounters water-saturated large pores. Then the LNAPL begins to migrate laterally over the water table and assumes the shape of a pancake (Dragun, 1988).

The pancake will tend to spread laterally as quickly as soil conditions will permit. Initially there may be sufficient head pressure to cause the light hydrocarbon to move a small distance up gradient, but the greatest speed will occur in the down-gradient direction. The pancake will migrate until it reaches residual saturation in the soil or until it reaches a zone of ground water discharge. Dragun (1988) also notes that the pancake will fluctuate vertically as the water table rises and falls in response to seasonal changes and to short-term rainfall events. The total amount of mobile hydrocarbons in the pancake will decrease as fluctuating mobile hydrocarbons coat soil particles and transform into residual saturation.

B3.0 MODELING NAPL MOVEMENT

The Working Group approach uses a linear distribution of contaminant between the vapor, water, and sorbed phases. The overriding assumption is that (TPHCWG, 1997):

Water Phase Mass Fraction + Vapor Phase Mass Fraction + Sorbed Mass Fraction = 100%

This linear distribution does not account for free product, and therefore, is not necessarily applicable when the concentrations found in the soils exceed saturation concentration (C_{sat}). Non-linear equations are required for describing partitioning and fate and transport when concentrations exceed C_{sat}.

The non-linear, one-dimensional contaminant transport equation can be written as:

$$\frac{\partial C}{\partial t} = -\frac{v}{R_d}\frac{\partial C}{\partial x} + \frac{D}{R_d}\frac{\partial^2 C}{\partial x^2} - \lambda C$$

Where: C = contaminant concentration in the ground water [mg/L]
t = time [s]
v = velocity of flow [m/s]
x = distance along the direction of flow [m]
D = dispersion coefficient [m^2/s]
R_d = retardation coefficient [unitless]
λ = first-order degradation constant [1/s]

This equation is based on the assumption that groundwater flow is laminar, the concentration of the contaminant is low enough to utilize linear sorption, and the contaminant degradation is first order (Hossain and Yonge, 1997). Many one-dimensional transport equations are available, and the American Society of Civil Engineers formed a task force to identify, classify, and evaluate those models that were used the most. Reddi *et al.* (1997) undertook a survey to identify those groundwater models most commonly used by state agencies and consulting firms. Models identified in the survey were classified by usage, function, and simulation. Pandit *et al.* (1997) provides a description and evaluation of those models identified by Reddi *et al.* (1997). Pandit *et al.* (1997) considered parametric description requirements of the various models, boundary condition requirements, strengths and limitations of the various models, and success in use of the various models by survey respondents. However, none of the models commonly used can deal with immiscible fluid transport.

In order to model the movement of a NAPL in a porous medium and estimate phase distributions, a coupled set of non-linear partial differential equations is required. The NAPL Simulator model, developed for the National Risk Management Research Laboratory of the U.S. EPA is the only model found in the public domain that provides that capability. The NAPL Simulator can be obtained through the Internet directly from the EPA Robert S. Kerr Environmental Research Center, Ada, Oklahoma. The EPA National Risk Management Research Laboratory describes the NAPL Simulator as (EPA, 1998):

Application: Simulation of the contamination of soils and aquifers which results from the release of organic liquids commonly referred to as Non-Aqueous Phase Liquids (NAPLs).

Processes: The simulator is applicable to three interrelated zones: a vadose zone which is in contact with the atmosphere, a capillary zone, and a water-table aquifer zone. Three mobile phases are accommodated: water, NAPL, and gas. The three-phase K-S-P sub-model accommodates capillary and fluid entrapment hysteresis. NAPL dissolution and volatilization are accounted for through rate-limited mass transfer sub-models.

The NAPL Simulator was developed to provide a physically complete subsurface flow and transport mathematical model to study the movement and fate of NAPL contaminants in near-surface granular soils. The NAPL Simulator uses a set of coupled non-linear partial differential equations (PDEs) which governs the temporal and spatial variability of the system, and a set of constitutive and thermodynamic equations that relates physically-based parameters occurring in the PDEs to the dependent variables. Two of the constitutive models included in the NAPL Simulator are (Guarnaccia *et al.*, 1997):

1. model of three-phase relative permeability-saturation-capillary pressure relationships which includes flow-path-history-dependent functionals (hysteresis), fluid entrapment considerations, and functional dependence on fluid and soil properties;
2. A model of rate-limited interphase mass transfer processes, including NAPL dissolution and volatilization.

The NAPL Simulator allows the user to consider problems in one, two, or three spatial dimensions while accommodating as many as three fluid phases (i.e., water, gas, and NAPL phases) in any combination. A complete discussion of the theory behind the multiple phase relationships, the non-linear partial differential equations used in the model, and the rules for the equations can be found in the documentation for the NAPL Simulator (Guarnaccia *et al.*, 1997). Two-dimensional and three-dimensional versions of the NAPL Simulator along with complete documentation are available for download directly from the Internet. A graphical user interface is also commercially available for the model.

Based on the foregoing discussion of NAPL characteristics in Section B2.0 and the capabilities included in the NAPL Simulator, it is recommended that the two-dimensional NAPL Simulator be used for Tier 1A risk assessment at Robins AFB, Georgia. The model should be used when concentrations found in the subsurface exceed the saturation concentrations for the effective hydrocarbon ranges. The use of this model will provide much more accurate estimates of down-gradient concentrations, volatilization, and groundwater concentrations than the linear equations used in the Working Group approach and the ASTM RBCA framework. Data from the NAPL Simulator can be input into the ASTM RBCA model and more accurate risk based screening levels (RBSLs) can be developed.

However, prior to using the model, the modeler should become familiar with the model and its input and output requirements using sample problems provided in the documentation and with the model software. In addition, Duke *et al.* (1998) points out that all models suffer from uncertainties in input conditions. These uncertainties arise from incomplete knowledge about existing subsurface conditions, such as transport characteristics caused by soil heterogeneity, and from statistical variability of future events over the period when transport is to be predicted,

such as annual rainfall. Duke *et al.* (1998) discusses sensitivity to input parameters and Monte Carlo simulation techniques to evaluate the variability in the results from the model based on those input parameters. It is recommended that the model user take the time to become familiar with this paper and attempt to identify the most sensitive input parameters prior to modeling the system for RBSL development.

B4.0 SUMMARY AND CONCLUSIONS

Total petroleum hydrocarbon (TPH) contaminant levels near the leak at Site 70, Robins AFB, Georgia, are anticipated to be at or above the saturation concentration for the petroleum hydrocarbon fractions. High levels of contamination at the site may cause the linear equations used by the Working Group and the ASTM RBCA model to be invalid. Therefore, an alternative means to model fate and transport of non-aqueous phase liquids is required for this site.

One fate and transport model in the public domain, NAPL Simulator, is applicable to NAPL transport in unsaturated and saturated zones of the subsurface. The NAPL Simulator can predict fate and transport of NAPLs and calculate the concentrations in multiple phases using non-linear partial differential equations. The model considers volatilization into air, adsorption by soils, dissolution into water, and transport of the NAPL along the groundwater hydraulic gradient. This model can assist in developing realistic RBSLs when the output from the model is fed into the ASTM RBCA framework.

It is recommended that the NAPL Simulator model be used in areas of Site 70 where concentrations found in the subsurface exceed the saturation concentration. Prior to using the model, time needs to be dedicated to identifying site-specific model input parameters and sensitivity of the model output to those parameters. In addition, the location within the RBCA framework for use of the NAPL Simulator output must be identified.

B5.0 REFERENCES

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APPENDIX C. SUMMARY INFORMATION ON SOIL GAS TRANSPORT FOR INDOOR AIR PATHWAY EXPOSURE

C1.0 INTRODUCTION

The transport of a hydrocarbon component in soil air and release to indoor air is an important pathway for human exposure. Based on our Phase I effort which resulted in the Field Investigative Work Plan in Appendix A, it is anticipated that the indoor air pathway exposure could be a factor at Robins Air Force Base (AFB). The component must move from within the soil to the soil surface and then move from the soil surface to soil air. The contaminated soil air can then migrate to the foundation of a dwelling and then enter the dwelling. The vapor phase movement of hydrocarbon components will depend primarily on diffusion and vapor pressure. Diffusion is the average rate of migration or movement of a chemical in air due to three different gradients (pressure, temperature, and concentration). Within a soil matrix, the controlling gradient is normally concentration. The tendency of a chemical to volatilize from an aqueous phase into soil air or atmosphere has been estimated by use of the Henry's Law constant, H_c. For very dilute solutions where the chemical compound's liquid mole fraction is less than 0.001, the vapor pressure of the compound is proportional to its liquid phase concentration:

$$VP = HC$$

where: VP = vapor pressure of the chemical [atm]
H_c = Henry's Law constant [atm-m^3/g-mole]
C = chemical concentration in soil water [g-mole/m^3]

If H_c is less than 5×10^{-6} atm-m^3/g-mole, the compound will not be found in the soil air. If H_c is greater than 5×10^{-3} atm-m^3/g-mole, the compound will be in the soil air extensively. Compounds with H_c values between 5×10^{-6} to 5×10^{-3} atm-m^3/g-mole will be present in both the soil air and soilwater phases. However, the presence of other organic compounds and soil particles as solids will greatly affect evaporation. The presence of other volatile solvents such as dissolved bulk hydrocarbons will reduce the volatilization rate in comparison to the volatilization rate of a pure solvent. The presence of the soil particles will also reduce the evaporation rate.

Many adsorption sites in soil will prefer to adsorb water and these sites in the unsaturated water zone or vadose will only adsorb some organic compounds when the soil moisture content is low. As a result, dry soils may hold some organic compounds that would volatilize under wetter soil conditions. Sanders and Talimcioglu (1997) noted that the predicted indoor air concentrations and inhaled doses for a contaminant varied by up to seven orders of magnitude depending on the soil moisture conditions.

The presence of higher molecular weight organics in soil water may also affect chemical movement. These higher molecular weight organics may enhance the water solubility of lower molecular weight hydrocarbons, thereby reducing these lower weight hydrocarbon compound vapor-phase concentrations (Dragun, 1988).

C2.0 VAPORIZATION FROM PETROLEUM SATURATED SOIL

As bulk hydrocarbons migrate, they will attach to soil particles via capillary forces. The retained bulk hydrocarbons on the soil particles are known as immobile or "residual saturation". The maximum amount of bulk hydrocarbon that can be retained by the soil is known as the "residual saturation capacity." If the bulk hydrocarbon spill quantity is small, the mass of the bulk hydrocarbon will quickly be exhausted as the bulk hydrocarbon is converted to residual saturation. If more bulk hydrocarbons are introduced and it exceeds the residual saturation capacity, the liquid bulk hydrocarbon continues its migration. Once the conversion is complete, the downward bulk hydrocarbon migration stops. Once the bulk hydrocarbons are attached to the soil particles, the product can remain, degradeby microbial action, leach to mitigating solvents, primarily water and other compounds, or vaporize to the soil gas.

Johnson *et al.* (1989) noted that when the contaminant concentration is low enough so that free adsorption sites are available on the soil (typically less than 100 mg/kg-soil), the adsorbed contaminant/vapor equilibrium can be modeled by the modified Brauner-Emmer-Teller equation. If the moisture content is great enough to form more than a monolayer of water molecules adhering to the soil surface (for sand that is 0.02 to 0.05 g-H_20/g-soil), then the vapor equilibrium appears to be governed by four phase partitioning (vapor, dissolved in soil moisture, sorbed to soil particles and free-residual, when the concentration exceeds the residual saturation capacity). Soil deeper than a foot typically exceeded the wilting point and sufficient moisture would be present. At low component concentration with no free-liquid or solid precipitate phase, the equilibrium vapor concentration (Equation C-1) is defined in terms of the Henry's Law constant.

$$C_{i,veq} = \frac{H_c C_{i,soil}}{\dfrac{H_c \in_A}{\rho_{soil}} + \theta_M + k_i} \qquad \text{Equation C-1}$$

where: $C_{i,veq}$ = Vapor concentration of component i in equilibrium with contaminant/soil matrix [mass-i/volume-vapor]
H_c = Henry's Law constant [cm^3 H_2O/cm^3 air]
$C_{i,soil}$ = Residual contamination level of i [g i/g soil]
$\in_A$ = Vapor-filled void fraction in soil matrix
ρ_{soil} = Soil matrix density [g/cm^3 soil]
θ_M = Soil moisture content [g H_2O/g soil]
k_i = Sorption Coefficient for i [(g i/g soil)/(g i/g H_20)]

However, Johnson *et al.* (1989) noted that for high residual contaminant levels in the soil, the vapor concentration of any component was limited and becomes:

$$C_{i,veq} = \frac{x_i P_{i,v} MW_i}{RT} \qquad \text{Equation C-2}$$

where: x_i = Mole fraction of component i in the free-liquid residual phase [unitless]
$P_{i,v}$ = Pure component vapor pressure of i [atm]
MW_i = Molecular weight of component i [g/mole]

R = Universal gas constant [82.1 cm^3-atm/mole-°K]
T = Absolute Temperature [°K]

Equation C-2 combines Raoult's Law and the Ideal Gas Law. Raoult's Law states that the pressure of high concentration liquid component is equal to the pure vapor pressure of the component times the liquid mole fraction of the component.

The RBCA model (Conner *et al.*, 1995) provides the user the option of using Raoult's Law for calculating the effective solubilities and vapor pressures of individual constituents within multiple-constituent mixtures. Once the petroleum product saturates the soil, non-aqueous phase liquids (NAPL) will form and most likely move toward soil unsaturated with petroleum product. In these conditions, use of the Raoult's Law will preclude overestimation of individual constituent solubilities and vapor pressures by correcting for the competing effects of multiple constituents. In a nutshell, Equation C-1 will report that the vapor concentration always increases with increasing residual contaminant levels whereas realistically, the equilibrium vapor concentration of any compound can not exceed its saturated vapor concentration as described by Equation C-2.

C3.0 RBCA MODEL

The RBCA model assumes the dwelling resides directly over the groundwater plume. Figure C-1 shows the diffusing vapors off-gassing from affected subsurface soils that penetrate through foundation cracks in an enclosed-space of the dwelling.

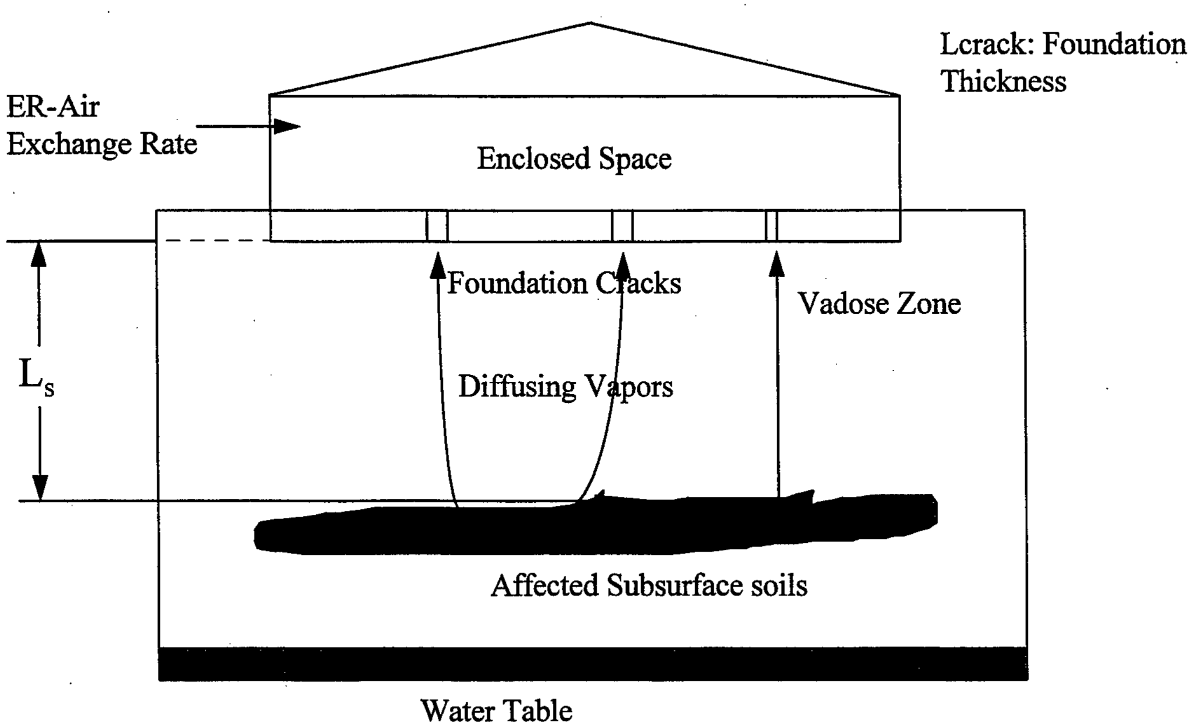

Figure C-1 Subsurface Soil Volatilization to Enclosed Space*
(* Adapted from Connor *et al.*, 1995)

ASTM E 1739-95 uses a volatilization factor, VF_{sesp} (subsurface soil to enclosed-space vapors) and defined it as follows in Equation C-3:

$$VF_{sesp} = \frac{\dfrac{(PF_{S-V})D_s^{eff}}{L_s(ER)L_B}}{1+\dfrac{D_s^{eff}}{ERL_s}+\dfrac{D_s^{eff}+L_{crack}}{(L_sD_{crack}^{eff})\times\eta}}\times 10^3\left[\frac{cm^3-kg}{m^3-g}\right] \qquad \text{Equation C-3}$$

where: Vf_{sesp} = Subsurface Soil to Enclosed Space Volatilization factor [(mg/m^3 air)/(mg/kg soil)]

PF_{S-V} = Soil/Vapor phase partitioning factor [unitless] and is defined as:

$$PF_{S-V} = \frac{H_c\rho_s}{\theta_{ws}+k_s\rho_s+H_c\theta_{as}}$$

H_c = Henry's Law Constant [cm^3 H_2O)/cm^3 air]
ρ_s = Soil Bulk Density [g soil-cm^3 soil]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3 H_20/cm^3 soil]
k_s = Soil-water sorption coefficient [g H_20/g soil]
θ_{as} = Volumetric air content in vadose zone soils [cm^3 air/cm^3 soil]
D^{eff}_s = Effective Diffusivity in vadose zone soil [cm^2/s] and is defined as:

$$D_s^{eff}\left[\frac{cm^2}{s}\right] = D^{air}\frac{\theta_{as}^{3.33}}{\theta_T^2}+D^{wat}\frac{1}{H_c}\times\frac{\theta_{ws}^{3.33}}{\theta_T^2}$$

D^{air} = Diffusion coefficient in air [cm^2/s]
θ_T = Total soil porosity [cm^3 pore-space/cm^3 soil]
D^{wat} = Diffusion coefficient in water [cm^2/s]
L_s = Depth to subsurface soil surfaces [cm]
ER = Enclosed-space air exchange rate [L/s]
L_B = Enclosed space volume/infiltration area ratio [cm]
D^{eff}_{crack} = Effective diffusivity through the foundation crack (cm^2/s) and is defined as:

$$D_{crack}^{eff}\left[\frac{cm^2}{s}\right] = D^{air}\frac{\theta_{acrack}^{3.33}}{\theta_T^2}+D^{wat}\frac{1}{H_c}\times\frac{\theta_{wcrack}^{3.33}}{\theta_T^2}$$

θ_{acrack} = Volumetric air content in foundation/wall cracks [cm^3 air/cm^3 total volume]
θ_{wcrack} = Volumetric water content in foundation/wall cracks [cm^3 H_2O/cm^3 soil]
L_{crack} = Enclosed space foundation or wall thickness [cm]
η = Areal fraction of cracks in foundations/walls [cm^2 cracks/cm^2 total area]

The RBCA model (Connor *et al.*, 1995) also calculates VF_{sesp} in Equation C-4 and uses the lesser value of Equation C-3 and Equation C-4 as the VF_{sesp}.

$$VF_{sesp} = \frac{\rho_s d_s}{L_B(ER)\tau} \times 10^3 \left[\frac{cm^3 - kg}{m^3 - g}\right]$$ Equation C-4

where: d_s = Thickness of affected subsurface soils [cm]
τ = Averaging time for vapor flux [s]

C4.0 OTHER MODELS

To identify suitable models for addressing a finite contaminant source, the Environmental Protection Agency (EPA) contracted to conduct a preliminary evaluation of a number of soil volatilization models, including volatilization models developed by Jury *et al.* (1983) and VLEACH, a multipathway model developed primarily to assess exposure through the ground water pathway. Study results show reasonable agreement (i.e., within a factor of 2) between emission predictions using the Jury model, but consistently lower predictions from VLEACH. However, a corrected VLEACH model, version 2.2, appears to provide emission estimates similar to the Jury model (EPA, 1996). Table C-1 notes some selected transport models for the unsaturated or vadose zone that address volatilization.

TABLE C-1 SELECTED TRANSPORT MODELS FOR THE VADOSE (CALARMARI, 1993)

Model	Characteristics	Fluid Flow Process	Solute Transport Processes
Jury *et al.*, 1983	Steady state	Average recharge rate; boundary layer model for evaporation	Partitioning, diffusion, degradation, 1st-order, volatilization and leaching
SESOIL	Numerical one-dimensional compartment	Statistical and seasonal data for the hydrological cycle	Advection, ad/desorption diffusion, degradation, 1st-order, volatilization
EXSOL	Numerical one-dimensional compartment	Average of statistical recharge rate; combination with SWATRER	Advection partitioning, dispersion, diffusion degradation, plant uptake, volatilization, metabolites
LEACHM	Numerical one-dimensional compartment	Transient hydraulic model using Richards Equation	Advection, ad/desorption, degradation, metabolites, volatilization

For the Jury *et al.* (1983) model, to estimate the average contaminant flux over 30 years, the time-dependent contaminant flux must be solved for various times and the results averaged. A computer program or spreadsheet can be used to calculate the instantaneous flux of contaminants at set intervals and numerically integrate the results to estimate the average contaminant flux. However, the time-step interval must be small enough (e.g., 1-day intervals) to ensure that the cumulative loss through volatilization is less than the total initial mass. Inadequate time steps can lead to mass-balance violations. To address this problem, EPA's Office of Research and Development, National Center for Environmental Assessment has developed a computer modeling program, EMSOFT. The computer program provides an average emission flux over time by using an analytical solution to the integral, thereby eliminating the problem of establishing adequate time steps for numerical integration. In addition, the EMSOFT model can account for water convection (i.e., leaching), and the impact of a soil-air boundary layer on the flux of contaminants with low Henry's law constants.

Johnson and Ettinger noted that in 1991 there were no accepted models for predicting the vapor intrusion rates of contaminant vapors into buildings, and there was considerable debate over which transport mechanisms govern the process. They presented a heuristic model for screening-level calculations which incorporated both convective and diffusive mechanisms and integrated contaminant soil and building foundation properties. This model could be used as a screeningtool to identify sites where more detailed numerical simulations of field sampling would be appropriate. They concluded that more experimental studies were required to compare to model predictions.

C5.0 TRANSPORT TO INDOOR AIR AND FACTORS AFFECTING INDOOR AIR CONCENTRATIONS

Fischer *et al.* (1996) conducted a field study of soil-gas transport of volatile organic compounds (VOCs) into a building at a site contaminated with gasoline. High VOC contaminant levels (i.e., 30 to 60 g/m^3) were measured in the soil gas 0.7 meter below the building. However, a sharp gradient in soil-gas VOC concentrations was noted between 0.1 and 0.7 meter where the VOC concentrations were reduced by a factor 1000. Measurements of both physical and biological soil characteristics suggest that there was a barrier to vertical transport in combination with microbial degradation which can explain the vertical concentration gradient. In addition, the dilution of soil gas entering the building by wind-driven building ventilation reduced the indoor air concentrations by an additional factor of 1000. Results of this study can not be directly applied to other sites as each site should be carefully examined to identify and separate physical and biotic effects (e.g., microbial degradation of VOCs). At this particular site, the measured water content showed a significant increase in the soil layer between 0.4 and 0.6 meter. Estimating the rate of vertical diffusive transport with a tracer gas, sulfur hexafluoride, indicated that a horizontal layer of water saturated soil only 2 mm thick would decrease the diffusive transport by one order of magnitude.

Sanders and Talimcioglu (1997) used the Integrated Moisture Plus Contaminant Transport (IMPACT) model in combination with the Jury *et al.* model to predict the effects of soil moisture on soil to indoor air exposure for volatile organic compounds. Without soil moisture movement, the chemical movement is solely via molecular diffusion. The Sanders and Talimcioglu model shows as the soil moisture was increased from 10 to 30% (volume/volume), the peak indoor air concentrations decreased from 450 μg/m^3 to 9 μg/m^3; the time of the peak concentration

increased from 25 days to 1,100 days. However, the effect of soil moisture on the long-term 30 year cumulative dose was less dramatic, varying by less than a factor of two. Sanders and Talimcioglu also noted that heavier soils, such as those with significant clay content, tend to retain higher levels of moisture than sandy soils. This higher moisture retention in combination with chemical degradation could greatly reduce indoor air concentrations and may result in contaminants never reaching the building foundations. They suggested that a lower diffusivity layer such as clay could be incorporated into a heterogeneous soils layer model that accounts for this rate-limiting layer.

C6.0 SUMMARY AND CONCLUSIONS

At Robins AFB, the degree of petroleum contamination near the building will need to be assessed. Assumptions used in the ASTM RBCA for volatilization include: 1) uniform constituent levels evenly distributed in soil and constant over exposure period, 2) no chemical of concern decay, 3) constant volatilization over the exposure period, and 4) conservative default values of foundation crack area and air exchange rate. These assumptions must be compared with the physical situation at Robins AFB and if they are not valid, an alternative model such as the Jury et. al. model with the EPA's EMSOFT may be required in a Tier 1A analysis.

C7.0 REFERENCES

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